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VOLUME 17 JULY, 1929 NUMBER 7

PROCEEDINGS
of
The Institute of Radio Engineers

General Information and Subscription Rates on Page 1072

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Eastern Great Lakes District Convention

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 17 July, 1929 Number 7

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The Institute of Radio Engineers

GENERAL INFORMATION

The PROCEEDINGS of the Institute is published monthly and contains papers and discussions thereon submitted for publication or for presentation before meetings of the Institute or its Sections. Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscription rates to the PROCEEDINGS for the current year are received rom non-members at the rate of $1.00 per copy or $10.00 per year. To foreign countries the rates are $1.10 per copy or $11.00 per year.

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Year Books for 1926, 1927, and 1928, containing general information, the Constitution and By-Laws, catalog of membership etc., are priced at seventy-five cents per copy per year.

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SUGGESTIONS FOR CONTRIBUTORS TO THE PROCEEDINGS

Preparation of Paper

Form—Manuscripts may be submitted by member and non-member contributors from any country. To be acceptable for publication manuscripts should be in English, in final form for publication, and accompanied by a summary of from 100 to 300 words. Papers should be typed double space with consecutive numbering of pages. Footnote references should be consecutively numbered and should appear at the foot of their respective pages. Each reference should contain author's name, title of article, name of journal, volume, page, month, and year. Generally, the sequence of presentation should be as follows: statement of problem; review of the subject in which the scope, object, and conclusions of previous investigations in the same field are covered; main body describing the apparatus, experiments, theoretical work, and results used in reaching the conclusions and their relation to present theory and practice; bibliography. The above pertains to the usual type of paper. To whatever type a contribution may belong, a close conformity to the spirit of these suggestions is recommended.

Illustrations—Use only jet black ink on white paper or tracing cloth. Cross-section paper used for graphs should not have more than four lines per inch. If finer ruled paper is used, the major division lines should be drawn in with black ink, omitting the finer divisions. In the latter case, only blue-lined paper can be accepted. Photographs must be very distinct, and must be printed on glossy white paper. Blueprinted illustrations of any kind cannot be used. All lettering should be $^3/_{16}$ in. high for an 8 x 10 in. figure. Legends for figures should be tabulated on a separate sheet, not lettered on the illustrations.

Mathematics—Fractions should be indicated by a slanting line. Use standard symbols. Decimals not preceded by whole numbers should be preceded by zero, as 0.016. Equations may be written in ink with subscript numbers, radicals, etc., in the desired proportion.

Abbreviations—Write a.c. and d.c., kc, μf, μμf, emf, mh, μh, henries, abscissas, antennas. Refer to figures as Fig. 1, Figs. 3 and 4, and to equations as (5). Number equations on the right in parentheses.

Summary—The summary should contain a statement of major conclusions reached, since summaries in many cases constitute the only source of information used in compiling scientific reference indexes. Abstracts printed in other journals, especially foreign, in most cases consist of summaries from published papers. The summary should explain as adequately as possible the major conclusions to a non-specialist in the subject. The summary should contain from 100 to 300 words, depending on the length of the paper.

Publication of Paper

Disposition—All manuscripts should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York City. They will be examined by the Committee on Meetings and Papers and by the Editor. Authors are advised as promptly as possible of the action taken, usually within one month.

Proofs—Galley proof is sent to the author. Only necessary corrections in typography should be made. *No new material is to be added.* Corrected proofs should be returned *promptly* to the Institute of Radio Engineers, 33 West 39th Street, New York City.

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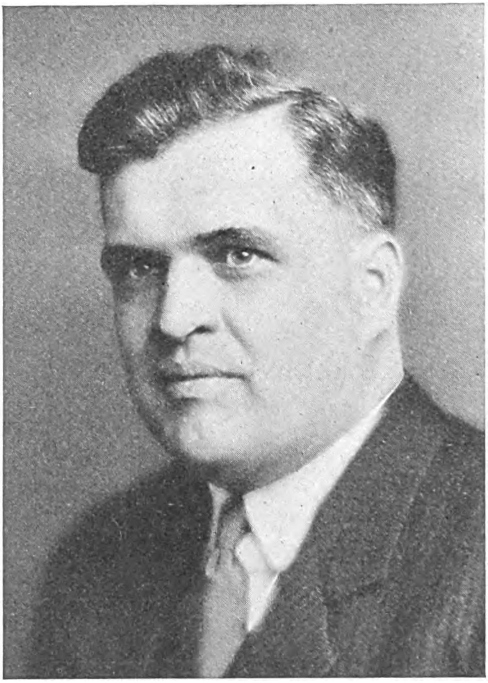

C. B. JOLLIFFE
Chairman, 1929 Convention Committee

All of the activities of the Institute are sponsored by and accomplished through the voluntary work of the many Institute Committees. The success of the recent Fourth Annual Convention in Washington is due to the splendid work of the various committees under the chairmanship of Dr. C. B. Jolliffe of the Bureau of Standards.

Associated with Dr. Jolliffe as chairmen of the subcommittees were: Thomas McL. Davis, registration and arrangements; Mrs. L. W. Austin, ladies' committee; S. S. Kirby, trips; F. P. Guthrie, dinner and entertainment; A. E. Kennelly, fellowship; W. G. H. Finch, publicity.

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June Meeting of the Board of Direction

At the June 5th meeting of the Board of Direction, the following Board members were present: A. Hoyt Taylor, President, Melville Eastham, Treasurer, Alfred N. Goldsmith, Junior Past President, John M. Clayton, Secretary, Arthur Batcheller, W. G. Cady, J. H. Dellinger, J. V. L. Hogan, L. M. Hull, and R. H. Marriott.

The following were transferred or elected to higher grades of membership in the Institute: Elected to the grade of Member: A. Zacek, Y. Watanabe, M. H. Schrenk, J. A. Ratcliffe, T. Nakamura, and H. Rothe. Transferred to the grade of Member: Carl H. Butman, L. C. Young, and W. H. Gerns.

One hundred and three Associate members and thirty Junior members were elected.

It was decided by the Board that in view of the growing interest of engineers in telegraph and telephone engineering methods as applied to radio problems, the Institute PROCEEDINGS will contain a moderate proportion of papers on the subject of telegraph, telephone, and cable engineering.

The following resolution dealing with a revision of the Institute's policy with regard to standardization was adopted by the Board:

> "The Board of Direction of the Institute, believing that the urgent need for reasonably rapid progress in radio standardization calls for revision of its policy with respect to the position of the Institute in standardization, (and particularly with respect to the need for conjoint consideration of such questions by representatives of numerous and widely diverse interests), now recognizes the scope of the Institute in standardization with respect to radio communication and the closely allied fields of science and technology as the following:
>
> 1. Nomenclature, symbols, and definitions.
> 2. Methods of testing apparatus, equipment, devices, and materials used in radio communication.
> 3. Acceptable limits for performance, ratings, capacities, operation, and other characteristics and standards for such apparatus, equipment and devices.
> 4. Standardization of sizes and dimensions, and electrical and mechanical characteristics of parts, apparatus equipment, and devices to provide for interchangeability and interworking, or economy in manufacture and use.
> 5. Standardization of specifications governing quality of material and methods of test therefor.
> 6. Establishment of provisions for safety of operating and other personnel in relation to radio equipment.

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"The Board accordingly adopts the policy of promoting such standardization through the activities of the Institute's Standardization Committee and through its sponsorship of the Sectional Committee on Radio of the American Standards Association."

As the official delegates of the Institute at the World Engineering Congress to be held in Tokio in October of 1929, the Board nominated F. B. Jewett and C. W. Latimer. Mr. Latimer is to present the symposium paper prepared in behalf of the Institute by a Committee composed of Alfred N. Goldsmith, E. L. Nelson, Julius Weinberger, D. G. Little, A. B. Clark, and J. H. Dellinger. The title of this contribution is "Technical Achievements in Broadcasting and its Relation to National and International Solidarity," the component parts of which are. Introduction, Radio Broadcast Transmitters and Related Transmission Phenomena, The National Broadcasting Company—A Technical Organization for Broadcasting, Speech Input Equipment, Wire Line Systems for National Broadcasting and Radio Broadcasting Regulation and Legislation.

Year Book and Standardization Report

To enable the 1929 Year Book to be mailed with the May issue of the PROCEEDINGS it was necessary to advance the mailing date of this issue considerably. Any member of the Institute not having received a copy of the Year Book by this time should notify the Institute Office.

The 1929 Year Book contains the complete report of the 1928 Committee on Standardization—representing a work of some one hundred pages. For the past two years the subcommittees of the Committee on Standardization and the main Committee itself, have been very active in the preparation of the 1928 report which represents the best thoughts on the subject of standardization the Institute was able to obtain throughout the entire world.

Reprint copies of the Standardization Report, alone, are available for distribution to members of the Institute free of charge upon application to the Institute office. The price to others is one ($1.00) dollar per copy.

European Radio Conference, Prague, 1929

*Translation of Final Protocol** of the European Radio Conference at Prague, 1929, signed by the delegations from the Telegraph Administrations of Germany, Austria, Belgium, Bulgaria, Denmark, Spain, Esthonia, Finland, France, Great Britain, Greece, Hungary, Irish Free State, Iceland, Italy, Latvia, Kingdom of Monaco, Norway, The Netherlands, Poland, Roumania, Kingdom of Serbs, Croats and

* French text in *Journal Teligraphique*, April, 1929.

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Slovenes, Sweden, Switzerland, Czechoslovakia, Turkey, and the Union of Soviet Socialist Republics.

A

The European Radio Conference of Prague, after having heard the delegations and experts present, and in conformity with the reports of its committees, recommends that the Administrations agree to the following:

I

The European Administrations recognize the necessity for them to act in common, to protect their mutual interest in broadcasting matters. They will take the necessary measures to conform as soon as possible to the plan of wave-length allocation which has been established by the Prague Conference. (Annex).

In the future the following manner of procedure will be adhered to:

Some modifications may be made in this plan either by direct arrangements between the interested Administrations (on condition that these arrangements do not interfere with the rights of third parties), or by collective action of the Administrations who have agreed to the provisions of the Prague Conference.

It is desirable that any new arrangements be made in consultation with the International Radiophone Union. These arrangements should be made known to other Administrations through the International Bureau of the Telegraph Union.

The collective action of these administrations will be exercised by the delegates authorized from each Administration, who will group themselves together into a committee to be assembled each time the majority of European Administrations pronounce themselves in favor of a request for such a meeting made by an Administration, through the intermediary of the International Bureau of the Telegraph Union, for the examination of important questions of mutual interest, and especially with a view to remedying serious faults which shall have manifested themselves in the application of the allocation plan now in effect; and to establish new allocation plans.

The International Radiophone Union may be used for expert advice when it is question of such a collective action. However, when it is to be called in as technical adviser and expert, the International Radiophone Union must be ready to receive with the same rights as its other members all the Government organizations carrying on broadcasting service, and must have received those which have made such a request for membership. The programs for meetings of the International Radiophone Union shall be notified to the Administrations through the International Bureau of the Telegraph Union.

The International Radiophone Union must, moreover, admit as observers, in all its organizations, representatives of Administrations who shall have expressed a wish to be so admitted, as well as of the International Telegraph Union, for the study of questions whose solution might necessitate the intervention or agreement of the said Administrations.

Transmitting stations will be required to maintain a stability of the waves used, with all the accuracy which technical methods permit.

The Belgian Administration is requested to be good enough, as a provisional measure, and with no charges nor responsibilities accruing to it, to have measured, in such a way as it may choose, the waves transmitted by broadcast

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stations, and to communicate the results of these measurements to all the Administrations through the intermediary of the International Bureau of the Telegraph Union.

II

The wave, 1124 meters (267 kc) used by the German criminal police is recognized as carrying on an international service from Germany with other European nations. In accordance with the provisions of Article 5, Paragraph 14 of the Washington Regulations, the waves of 89.5 kc (3350 m) and 45 kc (6660 m) are allocated for synoptic meteorological messages.

B

The Conference has decided to request the Czechoslovak Administration to be kind enough to express to the Administration of the Netherlands its desire to have the following questions studied by the C.C.I.R. at the next meeting at the Hague:

1. The proper separation to be maintained between wavelengths for radio transmissions of all kinds.
2. Stability control for all radio transmissions.
3. The allocation of short waves for aviation and for the criminal police.
4. The allocation of short waves for national services.
5. Power limitation for broadcast stations, and the proper formula to be used for regulating such limitation.
6. Frequency separation in cycles to be maintained between stations in adjacent bands.
7. Study of the organization for a permanent international service for frequency measurements.

C

The Conference adopts the following resolutions:

1. **Concerning the Plan of Prague.**

It is desirable that the Administrations:

a. Reduce to the greatest extent possible, in conformity with national requirements, the number of broadcasting stations of low power; and limit in the future, in the band from 200–545 meters, the power of stations to the absolutely necessary value required to carry on a suitable service within the normal and regular service area defined by the laws of radio propagation.

b. Should use, whenever circumstances permit it, for stations of local or even regional interest, common national waves, carefully synchronized, and working on an exclusive wave for the transmission of the same program.

c. Carry on the strictest regulation requiring broadcasting transmitters to give reasonable guarantees from a technical standpoint as to their operation, and especially to require such stations to take all possible precautions to avoid transmission of harmonics of the fundamental wave, and not to modulate beyond reasonable limits.

d. Formulate the strictest requirements in order that transmissions from other radio services working outside the broadcast bands should be free from harmonics capable of interfering with radiotelephone transmissions.

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e. Should study from now on, in view of the Madrid Conference, a better arrangement of wavelength bands allocated to different radio services, seeking for each type of transmission, in the light of technical progress, the wavelength bands most appropriate for such services, which would probably permit a notable increase of the possibilities available to satisfy the legitimate needs of broadcasting.

2. Concerning Call Letters and Amateur Stations.

It is desirable that:

a. Call letters of the International Series should be assigned to all radiotelegraph stations capable of causing international interference, except military and radiobeacon services. However, concerning military stations, the Administrations retain their right to assign or not to assign to them call leters of the international series.

b. The Administrations shall send to the International Bureau of the Telegraph Union a sufficient number of copies of the documents containing the provisions which they have drawn up for amateur stations. The Bureau will distribute them to other Administrations, who will thus be able to take note of them in the drawing up of their own regulations.

c. The Administrations which publish a list of amateur stations will send a copy to each Administration requesting it.

d. Irregularities found in amateur transmitting stations will be communicated to the interested Administration, and also to prevent any delay in these communications each administration will also notify the International Bureau of the Telegraph Union the address of the department which has charge of amateur regulation when such a department has not the ordinary Administration address.

3. Concerning waves used for aviation, it is desirable that the authorities of all the European countries should study the possibility of restricting the use by aviation of the wavelength band above 1340 meters (below 224 kc).

4. Concerning the interference caused by mobile and coast stations.

It is desirable:

That the different countries hasten as far as possible the modernization of the coast and ship stations, especially those which exchange many messages.

That by a more strict observance and a more judicious application of the Washington Regulations, especially by forbidding the transmission of superfluous signals, and the use of inordinately high power, a reduction should already be taking place, as far as possible, in the interference which coast and marine stations using damped waves cause to broadcasting services.

The Conference, as a result of this, requests the Administrations to be good enough:

To study the possibility, in so far as it shall be deemed desirable and practicable, of restricting transmissions on damped waves during the hours used by broadcasting stations.

To make sure that ship stations are adjusted and remain adjusted as accurately as possible upon their working waves, and that the damping of these waves be reduced to a minimum.

5. Concerning the work of the C.C.I.R.

It is desirable that the Administrations should carry on studies and pre-

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liminary tests which would be of such a nature as to facilitate the work of the C.C.I.R. which will meet at The Hague during the month of September, 1929.

6. Concerning the limits of power for broadcasting stations.

It is desirable, at least for a certain period, that countries limit the power of new or reconstructed broadcasting stations to a minimum value sufficient for the services to be carried on. The proposal has been made to take as a figure for such a power limitation 60 kilowatts in the antenna.

The C.C.I.R. is requested to determine whether a limitation on the effectiveness of broadcasting stations is practically possible, and according to what formula this limitation might in that case be determined.

7. Concerning the monitoring of waves, the Conference passed a resolution that a permanent arrangement for measuring frequencies used in radio services be organized.

The Conference recommends to the Administrations of Germany, England France, Italy and the U.R.S.S.:

a. To proceed to periodic measurements and to make periodic reports of the results to all the Administrations through the International Bureau of the Telegraph Union.

b. To put their measurement agencies at the disposal of the interested Administrations, in cases of interference, for the measurement of the frequencies in question.

The Conference invites the U.R.S.I. and the International Radiophone Union to cooperate with the above-mentioned agencies, giving them their scientific and technical collaboration.

The Conference requests Administrations having stations suitable for the periodic transmission of standard frequencies to inform the Administration of the Netherlands of the characteristics of these stations (frequency band, power, etc.) in order that the C.C.I.R. might study cooperative organization of these stations.

There are annexed to this protocol reports of the committees and subcommittees, as well as the minutes of the committees and of the plenary sessions.

Done at Prague, April 13, 1929

For Germany:—Otto Arendt, Dr. Steidle, Dr. Harbich, Munch.

For Austria:—Ing. Hans Pfeuffer.

For Belgium:—R. Corteil, Jean Marique.

For Bulgaria:—Tz. Christoff, Dr. R. Mednicaroff.

For Denmark:—C. Mondrup, C. Lerche, K. Christiansen.

For Spain:—Federico Aznar.

For Esthonia:—G. Jallajas.

For Finland:—V. Ylostalo.

For France:—Ferrie, Serre, M. Pellenc, Hamel, Chanton, Paszkiewicz.

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For Poland:—Eugene Stallinger.
For Roumania:—Constantinesco.
For Kingdom of the Serbs, Croats, and Slovenes:—Ing. Claude Kotal, Ing. Mario Osana, Ing. Robert Weege.
For Sweden:—Seth Ljungqvist, Arthur Karlsson, H. Nordenmark.
For Switzerland:—Dr. Reinhold Furrer, E. Nussbaum.
For Czechoslovakia:—Ing. Strnad, Frant. Pixa, Stanislav Chocholin, Dr. Otto Kucera, Ing. A. Steinbach, Dr. Burda, Ing. Singer, Dr. Jar. Svoboda, Ing. Josef Stransky.
For Turkey:—M. Mazhar.
For the Union of Socialist Soviet Republics:—A. Vassiliev, L. Eichenwald.

ANNEX

Allocation of Wavelengths

According to the Plan of Prague, Becoming Effective June 30, 1929

Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
160	1875	Holland	(Huizen)
167	1800	Finland	(Lahti)
174	1725	France	(Radio Paris)
183.5	1635	Germany	(Zeesen)
193.0	1533	Great Britain	(Daventry)
202.5	1481	U.R.S.S.	(Moscou)*
207.5	1444	Aviation services and Eiffel Tower	
212.5	1411	Poland	(Varsovie)
217.5	1380	Aviation services	
222.5	1348	Sweden	(Motala)
230	1304	U.R.S.S.	(Kharkov)*
250	1200	Turkey	(Stamboul)**
		Iceland	(Reykjavik)**

* The U.R.S.S. did not participate in the Washington Conference.

** The use of these waves, which are situated in a band not allocated to broadcasting by the Regulations annexed to the Washington Convention, is authorized, provisionally, under the express condition that stations using these waves shall not interfere with the services occupying this band.

(See Article 5, Paragraph 1, of the Regulations.)

Particularly, the transmission of these stations must not be allowed to make inoperative alarm signals, distress signals, security or urgency signals transmitted on the wave 500 kc (600 m) and on 333 kc (900 m).

In case of interference the interested Administrations will do their best to seek another suitable solution.

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Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
260	1153	Denmark	(Kalundborg)
280	1072	Norway	(X)**
297	1010	Switzerland	(Bale)**
320	930	U.R.S.S.	(Moscou C.C.S.P.)*
364	825	U.R.S.S.	(Moscou)*
375	800	U.R.S.S.	(Kiev)*
385	778	U.R.S.S.	(Petrozavodsk)*
395	760	Switzerland	(Geneva)**
442	680	Switzerland	(Lausanne)**
527	572	Germany	(Fribourg)**
		Kingdom of Serbs Croats and Slovenes	(Ljubljana)**
531.5	565	U.R.S.S.	(Smolensk)*
536	560	Germany	(Augsbourg)**
545	550	Hungary	(Hanover)**
554	542	Sweden	(Budapest)***
563	533	Germany	
572	525	Latvia	
581	517	Austria	
585.5	511	U.R.S.S.	(Arkhangelsk)*
590	509	Belgium	
599	501	Italy	
603.5	497	U.R.S.S.	(Moscou)*
608	493	Norway	
617	487	Czechoslovakia	
621.5	483	U.R.S.S.	(Gomel)*
626	479	Great Britain	
630.5	476	U.R.S.S.	(Simferopol)*
635	473	Germany	
644	466	France	(Lyon La Doua)
653	459	Switzerland	
666.5	450	U.R.S.S.	(Moscou S.P.)*
662	453	Common, No. 1	
671	447	France	(Paris P.T.T.)
680	441	Italy	
689	436	Sweden	
698	429	Kingdom of S. C. and S.	
702.5	427	U.R.S.S.	(Kharkov)*
707	424	Spain	
716	418	Germany	
725	413	Ireland	
729.5	411	U.R.S.S.	(Odessa)*
734	408	Poland	
743	403	Switzerland	
747.5	401	U.R.S.S.	(Koursk)*
752	399	Great Britain	
761	394	Roumania	
770	390	Germany	
779	385	Poland—Italy†	
783.5	383	U.R.S.S.	(Dnepropetrovsk)*
788	381	France	
792.5	379	U.R.S.S.	(Artemovsk)*
797	377	Great Britain	
806	372	Germany	
810.5	370	U.R.S.S.	(Tver)*
815	368	Spain	
819.5	366	U.R.S.S.	(Nikolaiev)*
824	364	Norway	
833	360	Germany	
842	356	Great Britain	
851	352	Austria	
855.5	351	U.R.S.S.	(Leningrad)*
860	349	Spain	
869	346	France	(Strasbourg)
878	342	Czechoslovakia	
887	339	Belgium	
891.5	337	U.R.S.S.	(Ivan-Voznesensk)*
896	335	Poland	
905	332	Italy	
914	329	France	(Montpellier)
923	325	Germany	
932	322	Sweden	
941	319	Bulgaria	

*** The wavelength allocated to Hungary will be brought back into the band allotted to broadcasting at the earliest favorable opportunity.

† Exclusive wave shared with the reservation that there shall not be any mutual interference.

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Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
950	316	France	(Marseilles)
959	313	Poland	
968	310	Great Britain	
977	307	Kingdom of S. C. and S.	
986	304	France	(Bordeuz Lafayette)
995	301	Great Britain	
1004	298	Holland	
1013	295	Esthonia	
1022	293	France and Czechoslovakia	(Limoges)
1031	291	Finland	
1040	289	Great Britain	
1049	286	France	(Reims)
1058	283	Portugal	
1067	281	Denmark	
1076	279	Czechoslovakia	
1085	276	Germany	
1094	274	Italy	
1103	272	France	(Rennes)
1112	270	Greece	
1121	268	Spain	
1130	265	France	(Lille)
1139	263	Czechoslovakia	
1148	261	Great Britain	
1157	259	Germany	
1166	257	Sweden	
1175	255	France	(Toulouse P.T.T.)
1184	253	Germany	
1193	251	Spain	
1202	250	Czechoslovakia	
1211	248	Italy	
1220	246	Common, No. 2	
1229	244	Albania (provisionally Poland)	
1238	242	Great Britain	
1247	240	Norway	
1256	239	Germany	
1265	237	Monaco—Nice—Corsica (shared)	
1274	235	Norway	
1283	234	Poland	
1292	232	Kingdom of S. C. and S.	
1301	231	Sweden	
1310	229	Spain	
1319	227	Germany	
1328	226	Roumania	
1337	225	Ireland	
1346	223	Luxemburg	
1355	221	Finland	
1364	220	France	
1373	218	Common, No. 3	
1382	217	Common, No. 4	
1391	216	Common, No. 5	
1400	214	Poland	
1410	213	Italy	
1420	211	Roumania	
1430	210	Hungary	
1440	208	Belgium	
1450	207	Common, No. 6	
1460	206	Common, No. 7	
1470	204	Common, No. 8	
1480	203	Common, No. 9	
1490	202	Common, No. 10	
1500	200	Free	

Note

The Conference has taken note of the existence of the station of Kaunas (Lithuania) which has used different waves between 155 kc (1935 m) and 151 kc (1990 m) for broadcasting services. This station having interfered with mobile services carried on by the station at Portishead (Great Britain) using the wave of 149 kc (2013 m), situated in the band reserved exclusively for mobile services, the Conference has directed the British Administration to make suitable negotias tions with the Administration of Lithuania, with a view to finding for the Kauna-station a wavelength which will not interfere with these mobile services.

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The Edison Fellowship

In honor of Thomas A. Edison and in commemoration of the 50th anniversary of his incandescent lamp, an Edison Fellowship for research in the General Electric research laboratory at Schenectady, N. Y., has been established. Its object is to help determine the fitness of the Fellow for industrial or scientific research by arranging for a year's research in that laboratory. The opportunity will be given to the selected candidate who has adequate training and who has done sufficient original work to have indicated an aptitude for research. The year's fellowship carries a grant of $3,000.

The selection from applicants will be made by the National Research Council with the advice of the Director of Research of the General Electric Company. The committee includes: Dr. George K. Burgess, director of the U. S. Bureau of Standards and chairman of the National Research Council, chairman of the committee; Dayton C. Miller, professor of physics of the Case School of Applied Science and chairman of the division of physical sciences of the National Research Council; James E. Mills, chief of the research division of Edgewood Arsenal and chairman of the division of chemistry of the National Research Council; and A. E. Kennelly, professor of electrical engineering at Harvard University. Dr. Willis R. Whitney, vice president and director of the research laboratory of the General Electric Company, represents that company.

The choice of research work will be influenced by the preference of the individual, and may be the continuation of studies already begun at college if suitable laboratory facilities are available, or the Fellow may work on new or specially selected projects, either independently or in cooperation with others.

Any research man wishing to apply for the fellowship who is able to begin a year's work this fall (1929) should send to the Director of the Research Laboratory, General Electric Company, Schenectady, N. Y., before July 4, relevant information about his training and a recent photograph, and should arrange for a separate letter of recommendation to be forwarded by someone with whom he has done original scientific work.

Application Form

On pages XIX-XX of this issue of the PROCEEDINGS there is printed an abridged form of application for membership in the Institute. It is believed that this blank, which pertains to the Associate grade only, will be found convenient by the membership for use in canvassing

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friends who are eligible for membership in the Institute, and by non-members for filling out and either mailing to the Secretary of the Institute in New York City, or handing to an officer of a local Section. Standard application forms for membership in the other grades will be sent upon request to the Secretary of the Institute.

Standard Frequency Transmissions by the Bureau of Standards

The schedule of standard frequency transmissions by the Bureau of Standards for the months of July to December (inclusive) appear below.

Eastern Standard Time	July 22	Aug. 20	Sept. 20	Oct. 21	Nov. 20	Dec. 20
10:00 P.M.	1500	4000	550	1600	4000	550
10:12	1700	4400	600	1800	4400	600
10:24	2000	4800	700	2000	4800	700
10:36	2300	5200	800	2400	5200	800
10:48	2700	5800	1000	2800	5800	1000
11:00	3100	6400	1200	3200	6400	1200
11:12	3500	7000	1400	3600	7000	1400
11:24	4000	7600	1500	4000	7600	1500

For further particulars as to the method of transmission, readers of the PROCEEDINGS are referred to the past issues of the PROCEEDINGS.

Persons using these transmissions are invited to send suggestions or comment to the Bureau of Standards, Washington, D. C. The Bureau will particularly welcome descriptions of ways in which the signals are used or other comment that might assist in increasing their usefulness.

Institute Meetings

1929 CONVENTION

The 1929 Convention was pronounced a great success by all members of the Institute who were present in Washington on May 13th to 15th. Over five hundred and fifty members and guests registered for the Convention.

With some modifications, the complete program as outlined in the April, 1929, issue of the PROCEEDINGS was carried out. Due to illness, Professor M. I. Pupin was unable to be present. Professor A. E. Kennelly, of Harvard University, presented an interesting lecture on "Radio and its Ways."

In addition to the reception for all members of the Institute by President Hoover, Mrs. Hoover held a reception for the ladies attending the Convention.

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Dr. and Mrs. Alexander Meissner and Dr. H. Rothe, from Berlin, Germany, and Professor Y. Watanabe of Japan made the trip to the United States to be present during all of the sessions.

At the banquet at the Mayflower Hotel on May 14th, at which four hundred and fifty members and guests were present, President Taylor announced that the 1930 Convention of the Institute is to be held in Toronto, Canada, during the month of June.

Eastern Great Lakes District Convention

Under the sponsorship of the Buffalo-Niagara, Cleveland, Rochester, and Toronto sections, a District Convention to which all members of the Institute are cordially invited, is being arranged for November 18–19, 1929 in Rochester.

A very interesting program is assured. The committee chairmen have been appointed as follows: executive committee, V. M. Graham; publicity committee, R. A. Hackbusch; transportation and accommodations, J. Eichman; fellowship, J. A. Victoreen; trips, A. L. Schoen; entertainment, E. C. Karker; ladies' entertainment, Mrs. Angevine; finance, H. J. Klumb.

The program will include inspection trips, a number of technical sessions and a banquet.

Proposed Cincinnati Section

Members of the Institute residing in the vicinity of Cincinnati, Ohio, have expressed the desire to organize a Cincinnati section of the Institute. W. W. Boes and R. H. Langley have been instrumental in the organization work.

The first organization meeting was held May 27th in the Chamber of Commerce Building, Cincinnati, Ohio. R. H. Langley and W. W. Boes presided. Short talks were given by O. H. Caldwell, former radio commissioner, C. D. Barbuleson, E. T. Flewelling, William Lukens, and R. H. Langley. Temporary officers were elected with the following results: R. H. Langley, chairman, and W. W. Boes, Secretary-Treasurer.

The next meeting of the proposed Cincinnati section will be held on September 9th.

Atlanta Section

The Atlanta section held a meeting May 8th in the Physics Laboratory, School of Technology, Atlanta, Ga. The meeting was presided over by the retiring chairman, Major W. Van Nostrand and Chairman Elect Henry P. Thornton. There was an attendance of ten members.

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Professor Rodger S. Strout of the Department of Physics in Georgia Institute of Technology presented a paper, "Piezo-Electric Crystals." Mr. Strout went into detail as regards oscillation characteristics of quartz crystals in various commercial and laboratory forms. The lecture was accompanied by slides showing crystals in associated circuits, temperature coefficient curves and holder spacing characteristics. He also illustrated the proper method of cutting and grinding for maximum accuracy and energy output. After the presentation of the paper an informal discussion took place, supplemented by actual oscillation tests of various crystals cut and ground.

Detroit Section

Fifty members and friends attended the meeting of the Detroit section on March 22nd in the Detroit News Building, Detroit, Michigan. A. B. Buchanan, chairman of the section, presided.

Henry N. Kozanowski, Department of Physics of the University of Michigan, presented a paper, "The Quartz Crystal Oscillator as a Standard of Frequency." The importance of a standard of frequency in radio research laboratories and in commercial practice was stressed. Frequency standards are divided in two classes: first, the primary standards such as the gravity pendulum, vacuum-tube maintained tuning fork, magnetostriction oscillator, and the piezo-electric oscillator; second, those which are calibrated from the above and are operated under constant conditions, as for instance, the Hartley and dynatron oscillators. A historical survey of the discovery of the piezo-electric effect by J. A. and P. Carrie in 1881, and its application to radio circuits by the work of W. G. Cady and G. W. Pierce followed. This included a qualitative discussion of the probable mechanism of oscillation of a piezo-electric plate and the development of a mathematical theory for the frequency of oscillation in terms of the material constants and the dimensions of the plate.

The methods of cutting, grinding, and mounting plates and their frequency control by the rheostatic means were explained in some detail.

Finally there was described the calibration of a crystal oscillator by means of the best note between the fundamental frequency of the crystal oscillations circuit and known harmonics of an oscillator whose frequency was entirely governed by the frequency of a tuning fork. The frequency of this fork was determined by using a synchronous motor telechron clock in the circuit maintaining it. In this manner it has been found possible to determine the frequency of the quartz crystal oscillator to an accuracy of 3 parts in 100,000.

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A general discussion followed the presentation of the paper.

The Detroit section held a meeting April 19th in the Detroit News Building, Detroit, Michigan. L. N. Holland, vice-chairman of the section, presided. Thirty-five members and friends attended the meeting.

J. E. Miller, instructor in Aeronautical Department of the University of Detroit, presented a paper, "Aircraft Radio Communication." The various phases of the present beacon system was explained. The transmitting range for beacons is 285–315 kc and for other communication 315–350 kc. The various means of utilizing radio transmission and reception as an accurate guide to a pilot when attempting a landing and the rotating loop method and the new polydirectional method which is still in the state of development were discussed. It was predicted that the present method of radio beacon would soon be replaced by the visual method. A motion picture on "Radio Beacons" was also shown.

A general discussion followed the presentation of the paper.

New York Meeting

President A. Hoyt Taylor presided at the New York meeting of the Institute held in the auditorium of the Engineering Societies Building, 33 West 39th Street, on June 5th.

Two papers were presented. The first, by Alan C. Rockwood and Warren R. Ferris, of the General Electric Company, was entitled "Microphonic Improvement in Vacuum Tubes."

The second paper, "A Study of the Output Power Obtained from Vacuum Tubes of Different Types," by H. A. Pidgeon and J. O. McNally, of the Bell Telephone Laboratories, was presented by Mr. McNally.

Both papers will be published in an early forthcoming issue of the Proceedings. No reprint copies are available.

Three hundred and fifty members of the Institute and guests attended the meeting, which is the last until the fall season opens on September 4th.

Philadelphia Section

On May 24th in the Bartol Laboratories of the Franklin Institute, Philadelphia, Pa., the Philadelphia section held a meeting. J. C. Van Horn, chairman of the section, presided. Fifteen members and guests attended. Gleason W. Kenrick and C. K. Jen, both of the Moore School of Electrical Engineering, University of Pennsylvania, presented a paper "Short Wave Radio Transmission Phenomena."

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The paper described the problems introduced by signal to noise ratio in limiting long distance transmission, and the need and uses of a quantitative transmission theory were outlined. Methods of obtaining requisite information as to the constitution of the upper atmosphere and the part played by Kennelly-Heaviside echo studies and field strength observations were pointed out. The results of further echo studies showing a run obtained during February giving abnormal heights and transmission phenomena including long time retardation echoes on 4435 kc were described. Some preliminary results of a study on field intensities observed at Philadelphia from WC1 and the perturbing effects of magnetic storms on this transmission were also outlined.

Seattle Section

On April 26th, the Seattle section held a meeting in Philosophy Hall, University of Washington, Seattle, Washington, presided over by A. V. Eastman, chairman of the section. Fifty-eight members attended.

A. V. Eastman presented a paper, "Shield Grid Tube as Intermediate R-F Amplifier." The paper described the action of the 22 tubes by comparing their characteristic curves with those of the 01A type. The method of measuring gain and selectivity of one or two 60-kc stages was explained. The r-f input was carefully shielded and varied by the IR drop method—the amplifier output was measured by microammeter readings. The curves showed many interesting advantages as well as shortcomings of the 22 type when used as i-f amplifiers.

Messrs. Libby, Deardorf, Carpenter, Kleist, and Willson participated in the discussion which followed.

A. V. Eastman, chairman, presided over a meeting of the Seattle section on May 24th in Philosophy Hall, Washington University, Seattle, Washington. Thirty-eight members and guests attended.

F. C. Dahlquist presented a paper, "The American Broadcast System." The paper explained the operation of the chain of stations on the American broadcast system. It also outlined the problems in each of the departments and showed the necessity of cooperation between the engineering, sales and program directing personnel. A few of the many problems and incidents of chain programs were told in a very interesting manner. Messrs. Budden, Clark, Kleist, and McNicholas participated in the discussion which followed.

A. V. Eastman announced that J. O. Tolmie had been chosen vice-chairman of the Seattle section.

After the meeting an inspection trip was made through radio station KJR.

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Toronto Section

On May 8th the Toronto section held a meeting in the Electrical Building, University of Toronto, Toronto, Canada, attended by sixty members. A. M. Patience, chairman of the section, presided.

B. DeF. Bayly presented a paper, "Radio-Frequency Amplifier Design." Messrs. Smith, Fox, and Richardson participated in the discussion which followed.

The election of officers was held which resulted in the election of V. G. Smith, chairman; G. E. Pipe, secretary; and F. D. Dalton, assistant secretary.

Personal Mention

Harold E. Dinger is now associated with the firm of Catterall, Inc., of Canton, Ohio, as radio engineer. He was formerly associated with the Schoch Studios of Alliance, Ohio.

E. R. Doyle, of Leeds and Northrup Company, Philadelphia, is now Assistant Director of Development in that organization. He was formerly Chief of the Electrical Division of the Department of Development.

Beverly Dudley, recently with the American Telephone and Telegraph Company at Chicago, Ill., has joined the staff of the American Radio Relay League at Hartford, Conn., in charge of Technical Information Service.

Walter R. Jones, until recently research engineer with the Federal Radio Corporation of Buffalo, is now sales engineer for Sylvania Products Company of Emporium, Pa.

Alfred L. Kissell has joined the staff of the Cuban Electrical Company at Havana. Mr. Kissell left the United Electric Light and Power Company to assume his new connection.

Alexander H. Knights, formerly test engineer with the Radio Corporation of America, has joined RCA Photophone as installation engineer.

A. S. Lemoine is now chief engineer of the Radio Department of the Royal Board of Telegraphs of Stockholm, Sweden.

G. Edgar Locke, until recently with the Patent Department, U. S. District Court for the Southern District of New York, is now associated with Electrical Research Products, Inc., as Supervisor of Installation Engineers.

Leo R. Mead is now laboratory assistant, Electrical Research Laboratories, Chicago, Ill.

Howard K. Morgan, formerly a student of the University of California, has become associated with the General Electric Company at Schenectady, N. Y. as radio engineer.

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GEOGRAPHICAL LOCATION OF MEMBERS ELECTED JUNE 5, 1929

Transferred to the Member grade

Dist. of Columbia	Washington, Federal Radio Comm.	Butnam, Carl H.
	Washington, 1018 Douglas St., N. E.	Young, Leo C.
New Jersey	Newark, Brandes Products Corp., 200 Mt. Pleasant Ave.	Gerns, Wm. H.

Elected to the Member grade

Dist. of Columbia	Washington, 1821 Rigga Place, N. W.	Schrenk, M. H.
New York	New York City, c/o Imperial Japanese Navy, Inspectors Office, 1 Madison Ave.	Nakamura, T.
Czechoslovakia	Prague 11, u Karlovu 5	Zzcek, August
England	Cambridge, Sidney Sussex College	Ratcliffe, J. A.
Germany	Berlin-Wilmersdorf. Guntzelstr. Berlin	Watanabe, Yasusi

Elected to the Associate grade

Alabama	Mobile, c/o Adams Glass Co., Inc., 17-19-21 So. Royal	Heyen, Rudolph J.
California	Hollywood, 1123 Poinsettia Drive	Signer, John J.
	Los Angeles, 4846 Rosewood Avenue	Cooper, George R.
	Los Angeles, 110 Center St.	Lee, Gilbert C.
	Los Angeles, 316 N. Reno St.	Ludlum, William T.
	Los Angeles, 921 W. 6th St.	McGonagil, H. A.
	Los Angeles, 2812 So. Main	Meyer, R. H.
	Los Angeles, 1609 Hipoint St.	Walter, Edward F.
	San Francisco, 1266 McAllister St. Apt. 8	Slavin, Samuel B.
	San Francisco, 715 Bush Street	Stanton, James M.
Connecticut	Hartford, 235 Collins St.	Heris, George
	Hazardville, South St.	Thompson, Stanley W.
Dist. of Columbia	Bellevue, U. S. N. Lab.	Wortman, E. C.
	Washington, National Electric Supply Co., 1330 New York Ave. N. W.	Burger, Clarence Walter
	Washington, 5013 8th St., N. W.	Seiler, Donald W.
	Washington, 1860 Clydesdale Place, N. W.	Struthers, Francis William
	Washington, c/o Federal Radio Comm.	Webster, Betheul M., Jr.
Illinois	Chicago, 4736 N. Racine Ave.	Alexander, Wayne
	Chicago, 1820 North Wells St.	Arnold, Lowell George
	Chicago, 2837 South St. Louis Ave.	Koutnik, J. A.
	Chicago, 5115 S. Winchester Ave.	Pletka, James
	Chicago, 5409 Agatite Ave.	Ramm, Carl H.
	Chicago, 312 N. Central Ave.	Walter, Wilbur Tayman
	Evergreen, 9343 Richmond Ave.	Randall, Lemuel E.
Indiana	Fort Wayne, 2925 Bowser Avenue	Ramm, Harold William
	Valparaiso, Stiles Hotel	Hayes, Arthur J.
	Valparaiso, 405 South Monroe St.	Munroe, A. D.
	Valparaiso, 505 E. Jefferson St.	Olinger, Robert
Iowa	Wapello, 312 Franklin Ave.	Fry, Lloyd L.
Massachusetts	Attleboro, Park Hotel	Bargamian, John
	Boston, Tropical Radio Tel. Co., 1 Federal St.	Kelly, Michael P.
	Cambridge, Stoughton Hall 14	Hazard, Willis Gilpin
	Jamaica Plain, Wireless Specialty Apparatus Co.	Blodgett, Edward D.
	Lynn, 87 Myrtle St.	Mayo, Royal E.
	Roxbury, 130 Marcella St.	Stone, Elmer F.
	Springfield, Am. Bosch Mag. Corp.	Benner, Howard J.
	Springfield, Am. Bosch Mag. Corp.	Bond, M. E.
	Springfield, Am. Bosch Mag. Corp.	Raskhodoff, Nicholas
	Winthrop, 23 Sagamore Ave.	Dalton, Robert E.
Michigan	Jackson, 306 Steward Ave.	Stoll, Paul A.
Mississippi	Jackson, 944 West Capitol St.	Meyers, James A., Jr.
Missouri	Independence, 819 W. Van Horn Road	Dennis, Ralph M.
	Independence, 630 Crysler St.	Johnston, Ivan F.
	Kansas City, 702 Shukert Bldg.	Blum, Sidney J.
	Kansas City, 1004 Davidson Bldg. 17th & Main	Clements, Thos. C.
	Kansas City, 1827 Norton	Haase, Edwin John
	Kansas City, 2112 Aberdeen Court	Hodge, Albert William
	Kansas City, 2722 Brighton Ave.	Kiefer, Harry Dukes
	Kansas City, 2503 Harrison St.	McCormick, Benjamin S.
	Kansas City, 4511 E. 23 St.	Payne, Harry Kenneth
	Kansas City, 2004 Prospect	Watter, George V.
	Kansas City, 3614 Brooklyn Ave.	Upham, Stewart W.
	Kansas City, 4012 Michigan St.	Vogel, Henry W.
	Kansas City, 1110 West 41st St.	Walter, Wm. J.

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Montana	Froid	Jacobs, Marcellus L.
New Jersey	Camden, 315 N. 27 St.	Sumner, Raymond Stokes
	East Orange, 137 Halsted St.	Feindel, Abbott
	Little Falls, R. F. D.	Farnsworth, Daniel W.
	Paterson, 489 Main St.	Trifari, Edmund
New York	Brooklyn, 253 Cumberland St.	Bower, James
	Brooklyn, 616 Bainbridge St.	Rehbein, Arthur Frederick
	Brooklyn, 1715 West 13 St.	Romeo, Anthony
	Flushing, 19 Smart Ave.	Sage, Frederic H.
	Jackson Heights, L. I. 125 22nd St.	Hickman, C. Nicholas
	New York City, 89 Cortlandt St.	Blan, Michael
	New York City, 1010 First Ave.	Haug, Joseph
	New York City, c/o R.C.A. Van Cortlandt Park So.	Krueger, Barton
	New York City, 117 E. 24th St.	Kunc, Frank
	New York City, R.C.A. 70 Van Cortlandt Park So.	Malter Louis
	New York City, Bell Tel. Labs., 463 West St.	Morrison, Howard
	New York City, 894 Riverside Drive	Rathner, Jack
	New York City, 64 East 103 St.	Rifkin, J. L.
	New York City, c/o General Delivery	Svendsen, A. V.
	New York City, 1820 Bryant Ave. Bronx	Trapkin, Jack H.
	Ozone Park, L. I.	Misenheimer, Rob't. G.
	Rochester, 145 So. Fitzhugh St.	Foster, Charles W.
	Rockville Centre, 259 Raymond Ave.	Lester, Paul Sabine
	Southampton, Box 269	Buckingham, Wm. D.
	Woodhaven, 7424 87th Ave.	Cooper, Gustavus
North Carolina	Ashville, Battery Co.	Xorellé, J. L.
Ohio	Cincinnati, 2042 Baltimore Ave.	Fisher, Ellwood T.
	Columbus, 28 W. Longview Ave.	Graham, J. P.
Oklahoma	Tulsa, 114 West Third St.	Pitcher, J. W.
	Tulsa, 627 Main St. S.	Wise, James Orr
	Tulsa, Willard Hotel	Robinson, L. L.
Pennsylvania	Allentown, 1801 Liberty St.	Kurtz, Clyde R.
	Chambersburg, Box 139	Ramsey, R. W.
	Clearfield, 326 Locust St.	Moyer, Elmo Emerson
	Easton, 1852 Freemansburg Ave.	Fox, Paul S.
	Philadelphia, 843 E. Price St.	Benge, J. R.
	Phildaelphia, 457 No. 12th St.	Mousley, Franklin
	Philadelphia, 5205 Akron St.	Travis, Charles
	Pittsburgh, 5866 Burchfield Ave.	Schlesinger, Louis B.
	Pottstown, 53 N. Charlotte St.	Roeller, Henry S.
Rhode Island	Providence, 663 Academy Ave.	Thomas, Harold
Utah	Spanish Fork	Fullmer, Don A.
Virginia	Roda, Box 42	Brien, William J.
Washington	Seattle, 113 E. 55th St.	Fitzpatrick, George Wm.
	Seattle, 503 Melrose Ave. No.	Hemerich, Walter A.
England	London SW 12, 42-A Balham Park Road	Green, Charles M.
Japan	Kawasaki, c/o The Tokyo Elec. Co.	Kuno, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Kuwajima, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Matsui, K.
	Kawasaki, c/o The Tokyo Elec. Co.	Miyauchi, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Ohtani, S.
	Kawasaki, c/o The Tokyo Elec. Co.	Otsuka, Y.
	Kawasaki, c/o The Tokyo Elec. Co.	So, Manabu
	Kawasaki, c/o The Tokyo Elec. Co.	Suga, Y.
	Kawasaki, c/o The Tokyo Elec. Co.	Suzuki, Hisao
	Sendai City, Harano-machi, Sending Station of JOHK, Sendai Broadcasting Station	Kanno, Gengo
	Tokyo, c/o Tokyo Central Broadcasting Station Atagoyamam	Fukushima, T.
	Near Tokyo, 1244 Hirahari, Magomemachi	Hamada, Shigenori
	Tokyo, c/o Tokyo Central Broadcasting Station, Atagoyamam	Koshikawa, Y.
	Tokyo, 59, Hitotsugicho, Akasakaku	Mita, S.
	Tokyo, c/o M. Kaneko, 2, 5-Chome, Kirakawa-Cho, Kojimachiku	Nagao, R.
	Tokyo, c/o Kaigun Kantokukan-Jimusho, 3, 1 Chome Uchisaiwai-cho, Kojimachiku	Nakajima, S.
South Africa	Tongaat, Natal	Howard, W. B.
South Australia	Eleanor Terrace, Murray Bridge	Miller, Francis G.
New Zealand	G. P. O. Box 188, Wellington	Russell-Boyle, H.

Elected to the Junior grade

Arkansas	Little Rock, 723 Wright Ave.	Stover, Arthur R., Jr.
Florida	Avon Park	Collins, Florine
Georgia	Atlanta, 933 Oak St.	Harrison, Richard H.
	Commerce	Hood, Sam
Illinois	Carpenter, Box 272	Bennett, Leslie W.
	Waukegan, 653 Mill Court	Herrmann, Albert, Jr.
Indiana	Connersville, 1948	Hamilton, Charles Ed.
	Valparaiso, 557 So. Locust St.	Cox, Hestor S.
	Valparaiso, 155 College Ave.	Johnson, Julien S.
	Valparaiso, 502 East Jefferson	Mealy, Max B.
	Valparaiso, 155 College Ave.	Reid, Herbert G.

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Maryland	Baltimore, 2449 Lauretta Ave	Ridenour, Wm. S.
Massachusetts	Boston, 570 Columbus Ave	Hatten, Arthur Thomas
	Dorchester, 894 Blue Hill Ave	Berkowitz, Louis
Michigan	Harbor Springs	Wright, Wilford C.
	Jackson, 302 Biddle St., E	Atkins, Carl Edward
New Jersey	Elizabeth, 419 Livingston St	Engel, Albert L.
	Pleasantville, 1507 S. Main St	English, James G.
New York	Brooklyn, 1121 Bedford Ave	Gray, De Wayne R.
	Brooklyn, 1272 E. 10th St	Charlat, Arnold
Ohio	Cleveland, 2915 E. 130th St. No. 10	Goetz, V. Wm.
	Cleveland, 2088 Cornell Road	Hybarger, H. Kenneth
	Payne	Huhuenin, Glenda
Oklahoma	Tulsa, KVOO	White, Karl K.
Pennsylvania	Allentown, 618 N. 12th St	Richardson, George A.
	Cynwyd, 407 State Road	March, Hallman W.
	Easton, 17 So. 6th St	Deutschman, Borah
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Dist. of Columbia	Washington, c/o Federal Radio Commission	Segal, Paul M.
	Washington, 3314 Newark St.	Mirick, C. B.

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Massachusetts	Waban, 100 Devon Road	Replogle, Delbert E.
Montana	Bozeman, c/o Montana State College	West, Glenn Edwin
New Jersey	Boonton, Radio Frequency Laboratories, Inc.	Wilmotte, R. M.
	Maplewood, 26 Berkeley Road	Pidgeon, Howard A.
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Pennsylvania	State College, 234 West Fairmount Ave.	Woodruff, Eugene C.
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	Leeds, 6 Blenheim Terrace, Northeastern School of Wireless	Russell, M. W. G.
	Manchester, British Broadcasting Corp.	Bird, R. J.
	Norbury, SW, 119 Headcorn Road	Shaw, A. C.
Germany	Berlin, Fritschestrasse 41, I, Charlottenburg	Roder, Hans
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	Wellington, G. P. O. Box 638	Thow, Keith H.
Scotland	Dundee, 1 Lochee Road	Lyne, R. H.
	Edinburgh, "Dunelm," 8 Cluny Drive	Beveridge, John A.
Spain	Cartagena, Calle de Ignacio Garcia No. 3	Ramirez Eduardo Garcia

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Alabama	Birmingham, 1315 Woodland Ave., W. E.	Giglio, James A.
Arkansas	Little Rock, c/o Marine Hotel, Room 850	Beem, Arthur W.
	North Little Rock, 1301 W. 9th St.	McDonald, A. H.
	Little Rock, 1311 Commer St.	Minor, Robert Lee
California	Glendale, 1341 5th St.	Bockoven, Lewis Murray
	Hollywood, 814 No. Vista St.	Schiefer, C. Vreeland
	Los Angeles, New City Hall, Room 317	Chapple, James M.
	Los Angeles, 2848 Westview St.	Gronoff, Harry
Colorado	Denver, 3839 Yates	McClimans, Abner E.
Dist. of Columbia	Washington, 4201 9th St., N. W.	Fugazzi, Frank J.
	Washington, 1722 19th St., Apt. 706	Hudiburg, Rea S.
	Washington, 917 North Carolina Ave., S. E.	Monar, Fred B.
	Washington, 5806 Colorado Ave.	Murray, Philip J.
	Washington, 3308 14th St., N. W.	Zinnecker, H. K.
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	Springfield, 1283 Carew St.	Morehouse, Dayton J.
	Walton, 42 Brookfield Road	Clark, R. W. 3rd
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	Kansas City, 2904 Forest Ave.	Gundy, Clarence Van
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	Kansas City, 4211 Wabash Ave.	Swett, J. P.
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	Fort Monmouth	Hoppough, Clay I.
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	Long Branch, 165 Garfield Ave.	Herson, Jacob S.
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India	Bombay, Indian Radio Telegraph Office	Enon, Ernest R.
Philippine Islands	Manila, 306 San Antonio Paco	Aglugub, Zacarias G.
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Part II

TECHNICAL PAPERS

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

A HIGH PRECISION STANDARD OF FREQUENCY*

By
W. A. Marrison
(Bell Telephone Laboratories Inc., New York, N. Y.)

Summary—*A new standard of frequency is described in which three 100,000-cycle quartz crystal-controlled oscillators of very high constancy are employed. These are interchecked automatically and continuously with a precision of about one part in one hundred million. They are checked daily in terms of radio time signals by the usual method employing a clock controlled by current maintained at a sub-multiple of the crystal frequency. Specially shaped crystals are used which have been adjusted to have temperature coefficients less than 0.0001 per cent per degree C.*

To meet the demands for increased precision in measurement and greater reliability of operation a new reference standard frequency system has been developed in the Bell Telephone Laboratories having an absolute accuracy that may be relied upon at all tames to better than one part in a million. This reference standard is similar in many respects to one described by Horton and Marrison a little over a year ago[1], but a number of important changes have been made which have contributed to increased accuracy and reliability.

The standard is based on the quartz crystal-controlled oscillator, with a synchronous motor-driven clock, used to determine its rate. It differs from others of the same general type in having a number of similar crystal-controlled oscillators which may be interchanged at will and which are intercompared continuously and automatically with a precision of one part in one hundred million. A number of improvements have been made in the crystal and mounting, and in the circuit, which justify this precision of measurement.

By far the most important element in a crystal-controlled oscillator is the crystal itself and great care was taken in selecting the type to be used in the new standard. A crystal was required as nearly independent as possible of ordinary variations in temperature and pressure and which could be mounted so as to vibrate freely. The effect of temperature appeared to be especially serious as the changes in frequency thus obtained with an ordinary crystal, even with the best commercial thermal regulators available, are greater than are caused by any other single factor in the new standard.

* Dewey decimal classification: R210. Original manuscript received by the Institute, May 17, 1929. Presented before New York meeting of the Institute, April 3, 1929.

[1] J. W. Horton and W. A. Marrison, "Precision Determination of Frequency," Proc. I. R. E., 16, 137; February, 1928.

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It has been known for some time that plates of quartz cut in the plane of the optic and electric axes usually have positive temperature coefficients and that plates cut in the plane of the optic axis but perpendicular to an electric axis have negative coefficients. It has also been known that oscillations may be produced in a crystal either paral-

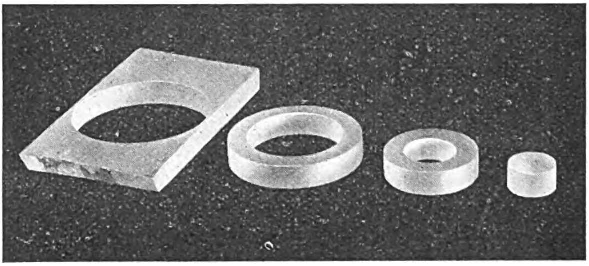

Fig. 1—Crystals Used in Preliminary Temperature Coefficient Tests.

lel to the impressed electric field or perpendicular to it, the socalled longitudinal and transverse effects. There is a certain amount of mechanical coupling between such different modes of vibration within the crystal, more or less close, depending upon the shape, and in particular depending upon the ratio of dimensions in the principal directions

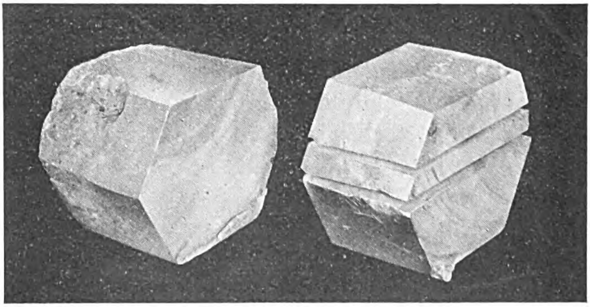

Fig. 2—Partly Assembled Crystal Showing the Relation of the Slab to the Crystal Axes.

of vibration. In view of these facts it was thought probable that crystals could be produced with such coupling between the modes which have inherently positive and negative coefficients that the resultant temperature coefficient would be nil.

Series of crystals of rectangular and circular shape were made to test this fundamental assumption. It was found that the temperature

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coefficient does vary with the shape of a resonator and, in particular, that crystals may be proportioned so as to have a coefficient that is practically nil. The relations between the temperature, coefficient and the dimensions in the case of rectangular plates, have been further studied in detail by F. R. Lack[2] of the Bell Telephone Laboratories.

In the first experiment performed with circular disks for this study a large disk was first cut and smaller ones cut from it, after measurement, to insure constancy of material, thickness and orientation with respect to the crystal axes. The parts remaining after three sizes of disks had been cut in this way, with the remainder of the slab from which they were obtained, are shown in Fig. 1. The slab is shown in the partly assembled original crystal in Fig. 2 to show the manner

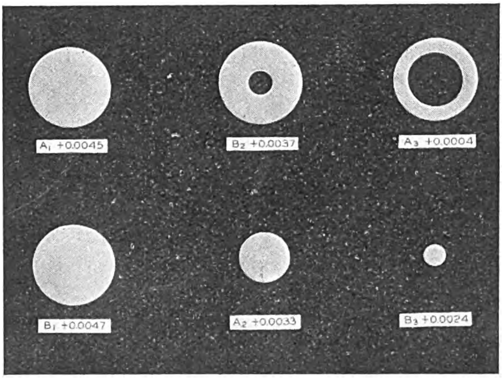

Fig. 3—Temperature Coefficients of Some Disks and Rings.

of cutting. With such circular disks it was found that at least one diameter could be found for which the temperature coefficient is very small throughout the entire room-temperature range.

Low temperature coefficient crystals obtained in this way are subject to the usual mounting difficulties, namely that the friction on the mounting considerably increases the decrement, and by an amount which may vary with time. A form of crystal is desired which can be mounted so that the parts vibrating at relatively large amplitude do not bear heavily on any portion of the mounting.

Further study of temperature coefficients showed that the rings remaining after the small disks had been cut from the larger one, shown in Fig. 1, have a temperature coefficient lower than disks of the same diameter and thickness. This is further illustrated in Fig. 3, which

[2] F. R. Lack, "Observations on Modes of Vibrations and Temperature Coefficients of Quartz Plates," Proc. I. R. E., 17, 1123; July, 1929.

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gives the temperature coefficient of two disks and the four parts remaining after holes of different diameters had been trepanned in them.

It is possible to make ring-shaped crystals having negligible temperature coefficients in a considerable range of frequencies, and, since the ring shape permits of an improved method of mounting in which

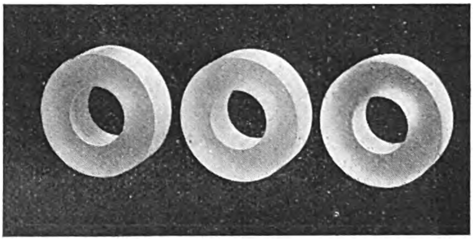

Fig. 4—Three 100,000-Cycle Low-Temperature Coefficient Rings used in Frequency Standard.

there is very little friction on the holder, they have been adopted for use in the present standard. Such a crystal having a frequency of 100,000 cycles is of substantial size and is reasonably easy to make and adjust. Three of the crystals used in the present standard, adjusted to 100,000 cycles, and having temperature coefficients less than one part in a million per degree C, are shown in Fig. 4.

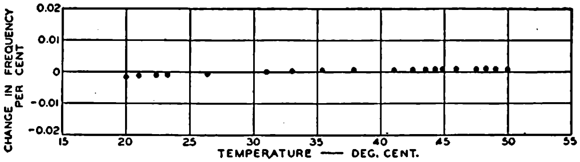

Fig. 5—Variation of Frequency with Temperature for a 100,000-Cycle Ring Crystal Adjusted for Low-Temperature Coefficient.

The variation of frequency with temperature for one of the ring-shaped crystals is given in Fig. 5, showing that it is very small over the usual room temperature range. All of the ring-shaped 100,000-cycle crystals made thus far are alike in having a coefficient which is small throughout this range[3]. The temperature coefficient of a disk of the same frequency having the same outside dimensions as the 100,000-cycle rings is approximately 30 parts in a million per degree C, more than thirty times that of the adjusted crystal.

[3] Where an accuracy of the order of only one part in 100,000 is desired, as in some portable standards, such a crystal could be employed without any form of temperature control.

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The manner in which the ring-shaped crystals are mounted in their operating position is shown in Fig. 6. The hole is shaped so that when the crystal hangs on a horizontal cylinder the point of contact is at a theoretical node for mechanical vibration. There is evidence of slight vibration where the central plane intersects the double conical hole, but it is small in comparison with that obtained at the outer

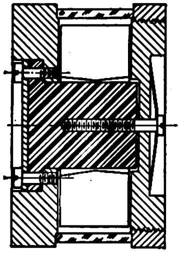

Fig. 6—Section of Crystal Mounting Showing Point Support.

surface where a crystal is usually supported. The decrement of the crystal when so mounted is considerably less than when it is supported on one of its plane surfaces.

In the mounting the crystal is spaced from the electrodes and is kept approximately central by means of paper spacers on each side. The crystal is free to move laterally in a narrow region but, since it is

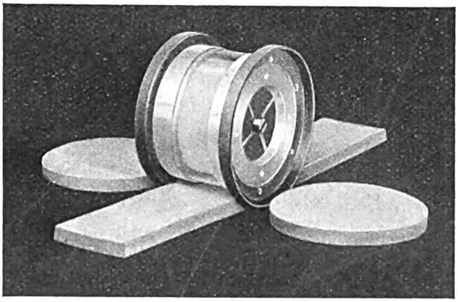

Fig. 7—Crystal Mounting with Crystal.

centrally located, the frequency is at a maximum value and hence a slight motion of the crystal to either side has only a second order effect on the frequency.

The variation of frequency with total electrode spacing is appreciable, but variations due to this factor are avoided by keeping the electrodes accurately spaced by means of a ring of pyrex glass. The temperature coefficient of pyrex is about one-quarter of that of crystal

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quartz perpendicular to the optic axis, so the variation in spacing that is obtained is due almost entirely to the expansion of the crystal. The effect on the frequency due to the differential thermal expansion of the crystal and crystal holder is, however, less than one part in 10^7 per degree C and so it may be neglected. If it is desired to eliminate this effect entirely, a spacer should be used having the same temperature coefficient of expansion as quartz perpendicular to the optic axis, but for practical purposes a material such as pyrex glass or fused quartz is entirely satisfactory.

The crystal holder is constructed so that a slight variation can be made in the total spacing between electrodes. Since the frequency varies with electrode spacing this can be used for making a slight ad-

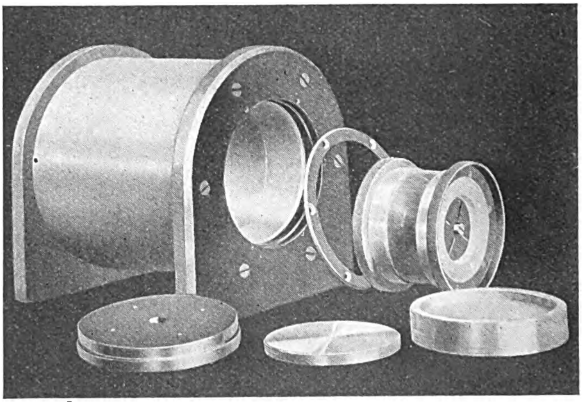

Fig. 8—Temperature Control Chamber with Crystal Mounting.

justment of frequency. The thread on the adjustable plate is kept tight by spring tension to prevent the spacing from varying irregularly. A crystal holder and a 100,000-cycle crystal are shown in Fig. 7.

Even though the crystal and its mounting have very low temperature coefficients, it is desirable to control their temperature, for which purpose the temperature controlling device shown in Fig. 8 has been constructed. It consists of a cylindrical aluminum shell with a wall about one inch thick, with a heater (not shown), and with a temperature responsive element in the wall to control the rate of heating. The aluminum shell has a metal plug that screws into the open end forming a chamber for the crystal which is then completely closed except for a small hole for electrical connections.

Since aluminum is a good thermal conductor the shell equalizes the temperature throughout the chamber and thus avoids the use of

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a fluid bath. The main heating coil is wound in a single layer over the whole curved surface of the aluminum cylinder, being separated from it only by the necessary electrical insulation. Auxiliary heating coils are wound also on the ends so as to distribute the heating as uniformly as possible. This, in effect, makes the short cylinder behave like a section from an infinite cylinder. To protect the thermostat from the effect of ambient temperature gradients the heating coil has an out-

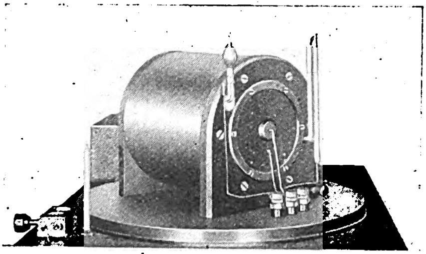

Fig. 9—Complete Temperature Control Unit.

side covering consisting of four layers each of thin felt and sheet copper spirally wound so that alternate layers are of copper and felt, the innermost layer being of felt and the outer one of copper. This is the covering that appears on the complete device shown in Fig. 9. This covering is very effective in reducing surface gradients since the conductivity in directions parallel to, and perpendicular to, the surface differ by a large ratio.

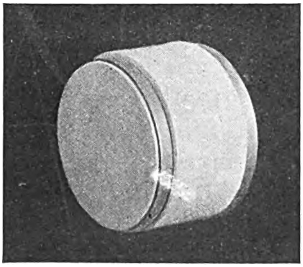

Fig. 10—Crystal Mounting with Felt Insulation.

The temperature of the shell rises and falls periodically by about 0.02 deg. C, but even this variation is prevented from reaching the crystal in its mounting by a layer of felt about half a centimeter thick surrounding the crystal holder. At the period of thermostat operation obtained the temperature variations actually reaching the crystal are reduced more than a thousand-fold. The complete temperature

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controlling device is shown mounted in its operating position in Fig. 9. One of the mounted crystals wrapped in its felt protecting layer is shown in Fig. 10.

To protect the resonator from humidity and pressure variations it is kept under a bell jar at a pressure slightly below atmospheric. With the crystals used the frequency varies approximately one part in a million for 10 cm of mercury change in pressure. It is aimed, therefore, to maintain the pressure constant to about ± 1 mm. A small mercury gauge within the bell jar indicates the pressure, which may be adjusted by a vacuum pump through a valve in the surface plate. The pressure within the bell jar is affected somewhat by the temperature, and in order to keep it within the required limits it is necessary to maintain a rough control of the temperature within the jar. The pressure gauge does not indicate a change in pressure due to a change in temperature, but will indicate any slow leak into the jar

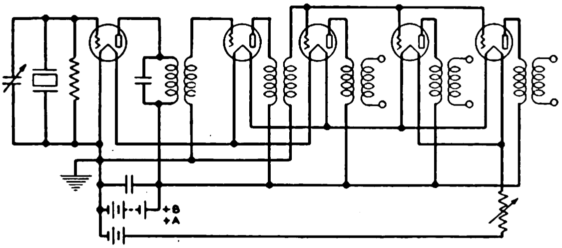

Fig. 11—Circuit of Standard Frequency Oscillator.

that may develop. A thermometer within the bell jar indicates the temperature, from which the change of pressure, and the correction of frequency due to it, may be computed if desired.

Since the frequency varies with the pressure surrounding the crystal an approximate adjustment of the frequency may be made conveniently by an adjustment of pressure.

The circuit of the crystal-controlled oscillator and the first amplifier stages is shown in Fig. 11. The oscillator is of the familiar type in which the crystal electrodes are connected to grid and ground and in which a tuned plate circuit is used. The great advantage in being able to ground one electrode was the major consideration in choosing this circuit. With this circuit, as in the one described a year ago,[1] it has been found possible to choose plate tuning elements such that slight variations in either the inductance or the capacity have little effect upon the frequency. For certain values of inductance and capacity the frequency, as a function of their product, takes on a maximum value. The adjustment that gives the maximum value of frequency is used,

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therefore, so that slight variations, such as those due to temperature coefficient and aging of the tuning elements, will have a negligible effect on the frequency.

The output circuit of the oscillator is very loosely coupled to three independent output amplifiers. This arrangement provides three independent output circuits free from mutual interference and unable to react to an appreciable extent on the crystal oscillator.

The final adjustment of frequency is made with a small cylindrical condenser, having a capacity of about 5 $\mu\mu$f, connected in parallel with the crystal electrodes. The size of this condenser is chosen such that

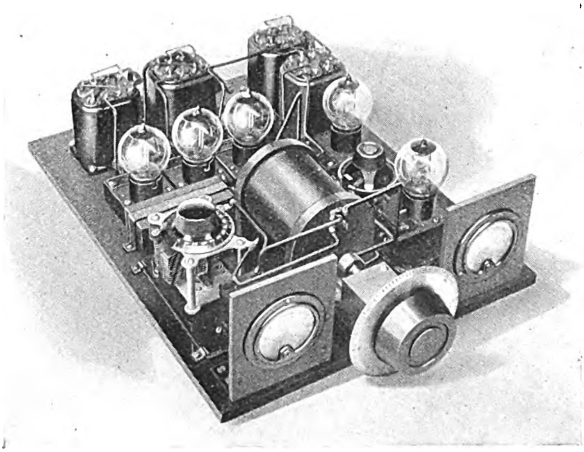

Fig. 12—Standard Frequency Oscillator without Shield.

an adjustment of one division on the dial corresponds to a change of frequency of about one part in a hundred million. There are 100 divisions on the dial and a total of 10 turns may be made corresponding to a total possible adjustment of about one part in 100,000. This condenser is shown at C in the circuit drawing.

The oscillator circuit, showing the tubes and transformers, the plate tuning elements, the filament and plate current meters, and the frequency adjusting condenser is shown in Fig. 12. The adjusting condenser is mounted between the meters and is controlled by the large knob and dial.

One complete oscillator unit, consisting of a 100,000-cycle crystal-controlled oscillator with three independent 100,000-cycle outputs, having a self-contained temperature and pressure controlled crystal,

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and having a temperature-controlled, electrically shielded circuit, is shown in Fig. 13.

The submultiple generator circuit that is used to obtain outputs at 10,000 cylces and 1000 cycles is shown in Fig. 14. It consists of an inherently unstable vacuum-tube oscillator with the tube operating on the curved part of its characteristic. The frequency of this oscillator may be controlled readily by any frequency which is a small multiple or submultiple of it. In this instance the oscillator is controlled by an input having the frequency of its tenth harmonic, the controlling high-frequency input being resistance coupled into the plate circuit of the lower frequency oscillator. The frequency of the controlled oscillator remains indefinitely at an exact submultiple of the controlling frequency.

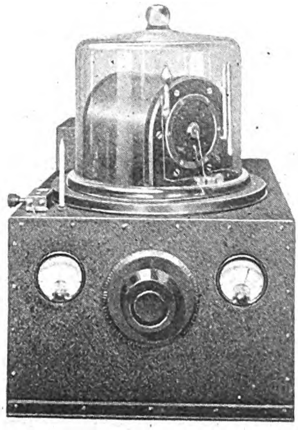

Fig. 13—One Complete 100,000-Cycle Standard Frequency Unit.

Two such circuits are used, one to obtain current at 10,000 cycles and one for 1000 cycles. Of course, additional amplifier circuits are required in order to supply outputs of considerable magnitude at these frequencies, and in such a way that there can be no reaction on the controlling circuits due to load variations or to stray currents at other frequencies fed backward through the output circuits.

A 1000-cycle motor, operated by current controlled at the 100th submultiple of the standard, drives generators for producing current at 100 cycles and 10 cycles. There are available, therefore, frequencies in decade steps from 100,000 cycles to 10, all controlled by the 100,000-cycle primary oscillator.

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The 1000-cycle motor is geared to a clock in such a way that, when the controlling frequency has its nominal value exactly, the clock keeps accurate time. In order to check the frequency of the system, therefore, it is only necessary to observe changes in rate of the clock so controlled.

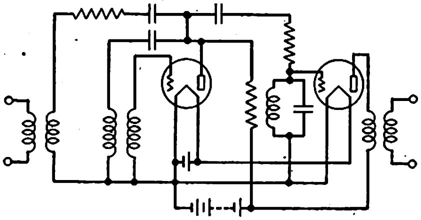

Fig. 14—Circuit of Sub-Multiple Generator.

An error of 0.864 second per day in the rate of the clock corresponds to an error in the frequency controlling it of one part in 100,000. It is possible to check the rate of the clock visually with an accuracy of about 0.2 second from audible time signals, but obviously this is not

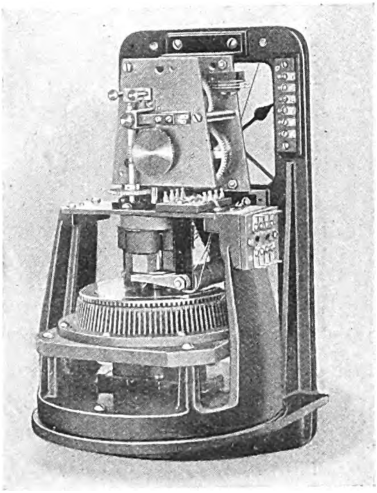

Fig. 15—1000-Cycle Synchronous Motor, Generators, and Clock.

sufficiently accurate for our purpose, giving an accuracy of only about one part in 400,000 in a day's observation. In order to facilitate the comparison with time signals, a contact operated by a cam driven by the 1000-cycle synchronous motor makes a contact once each second, or to be exact, once for each 100,000 cycles of the primary oscillator.

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This contact operates one element of a two-element recorder while time signals operate the other. Comparisons may thus be made by actual measurements on tape and can be made with greater accuracy than can be judged by eye.

The 1000-cycle synchronous motor, with its two generators and induction starting motor geared to the clock, is shown in Fig. 15. In this figure the seconds contact mechanism may be seen on the vertical shaft intermediate between the shaft of the motor and the second-hand shaft of the clock.

The assembled rotor of this motor is shown in Fig. 16. The large disk is the 1000-cycle motor rotor. The disk below it is a hollow steel flywheel filled with mercury used to reduce hunting. The small rotor below the flywheel is the rotor of the unipolar 10-cycle generator. The disk above the motor rotor is the armature of the 100-cycle generator. The squirrel cage armature of an induction motor for starting is immediately above the 100-cycle generator rotor.

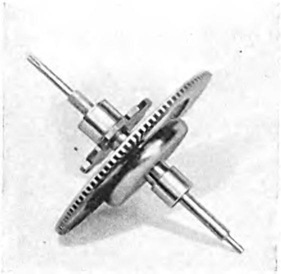

Fig. 16—Rotor of Motor Generator.

A single constant frequency generator is no longer sufficiently reliable as a standard of frequency of high precision and, as has been the practice where accurate time standards are maintained, three similar units have been installed. Means are provided for interchecking them continuously and automatically with the highest precision justified. The use of three such generators with means for interchecking them makes it possible to determine very quickly if and when one generator fails to operate properly.

Only one submultiple generator, clock, and multiple output amplifier is provided, but a special 3-way switch is used by means of which any one of the three primary oscillators may be selected and used as the controlling unit. The oscillators may be interchanged in any order without interrupting the circuits controlled by them.

In the method used for automatic interchecking a fourth oscillator unit is used, identical with the other three except that the frequency

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is maintained at a slightly different value. The difference between the frequency of this oscillator and that of the other three is kept at about 1 cycle in 10 seconds. The number of beats between the fourth oscillator and each of the other three oscillators is recorded automatically during each 1,000-second interval. The number of beats thus recorded is approximately 100 during each interval.

In 1,000 seconds each oscillator generates approximately one hundred million waves. The numbers that are recorded are, therefore, the number of parts in one hundred million by which oscillator No. 4 differs from each of the three primary oscillators during the interval. If the numbers recorded during successive intervals remain the same, the oscillators either did not vary, or they all varied in the same direction by the same number of cycles. If the numbers recorded in successive intervals vary by say 1, 2 or 5, it means that the oscillators have drifted, relative to each other, by so many parts in one hundred million.

Designating the frequencies of the four oscillators by

$$f_1,\ f_2,\ f_3,\ f_4 \tag{1}$$

the three numbers recorded are

$$1000(f_4-f_1),\quad 1000(f_4-f_2),\quad 1000(f_4-f_3). \tag{2}$$

The mean of these numbers is

$$1000\left(f_4-\frac{f_1+f_2+f_3}{3}\right). \tag{3}$$

If we subtract each of the original three recorded numbers from the mean we obtain

$$1000\left(f_1-\frac{f_1+f_2+f_3}{3}\right)=\delta_1 \tag{4}$$

$$1000\left(f_2-\frac{f_1+f_2+f_3}{3}\right)=\delta_2 \tag{5}$$

$$1000\left(f_3-\frac{f_1+f_2+f_3}{3}\right)=\delta_3 \tag{6}$$

Thus we may compute readily the performance of each of the four oscillators referred to the mean of the three similar primary oscillators. It is obvious that the accuracy of intercomparison of the three similar oscillators does not in any way depend upon the constancy of

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oscillator No. 4. For convenience in reducing the results, however, it is controlled as carefully as the others.

The records and computed results for approximately ten hours are given in Table I. During this time the largest relative variation between any two of the four oscillators taken in pairs was 5 parts in 10^8. The random variations between 1000-second periods appear to be in

TABLE I

A Ten-Hour Record Obtained by Means of the Beat Recorder

The columns δ_1, δ_2, and δ_3 indicate the difference between each oscillator and the mean of the three during each 1000-second interval expressed in parts in one hundred million.

Serial	Mean	(f_4-f_3)	δ_3	(f_4-f_2)	δ_2	(f_4-f_1)	δ_1
45	86	92	+6	98	+12	69	−17
44	86	92	+6	98	+12	68	−18
43	87	92	+5	99	+12	69	−18
42	87	93	+6	99	+12	70	−17
41	86	92	+6	99	+13	68	−18
40	87	94	+7	98	+11	68	−19
39	86	93	+7	99	+13	67	−19
38	87	94	+7	99	+12	67	−20
37	86	93	+7	99	+13	67	−19
36	87	95	+8	99	+12	66	−21
35	86	93	+7	98	+12	67	−19
34	87	95	+8	100	+13	66	−21
33	87	94	+7	100	+13	66	−21
32	87	95	+8	101	+13	66	−21
31	87	95	+8	101	+14	65	−22
30	87	94	+7	101	+14	66	−21
29	87	94	+7	101	+14	65	−22
28	87	95	+8	101	+14	66	−21
27	87	94	+7	102	+15	65	−22
26	87	95	+8	101	+14	66	−21
25	88	94	+6	103	+15	66	−22
24	88	94	+6	103	+15	68	−20
23	89	96	+7	103	+14	68	−21
22	89	95	+6	103	+14	68	−21
21	89	95	+6	103	+14	68	−21
20	90	95	+5	105	+15	69	−21
19	89	95	+6	103	+14	69	−20
18	89	95	+6	104	+15	68	−21
17	88	94	+6	102	+14	68	−20
16	89	95	+6	104	+15	69	−20
15	89	95	+6	102	+13	69	−20
14	89	95	+6	103	+14	69	−20
13	89	95	+6	102	+13	69	−20
12	89	94	+5	103	+14	70	−19
11	89	95	+6	103	+14	69	−20
10	90	95	+5	103	+13	71	−19
9	89	95	+6	103	+14	70	−19
8	89	95	+6	103	+14	69	−20
7	89	94	+5	103	+14	70	−19

the order of one or two parts in a hundred million. These random variations are superposed on slow drifts of a quasi-periodic nature probably caused by temperature changes in the circuit and amounting to less than one part in ten million. In addition to these effects a slow, steady drift is expected due to a settling-down of the oscillator circuit and the crystal in its mounting as well as due to aging of the vacuum tubes and even of the crystal itself. The effects of aging can, of course, only be determined after long continued operation.

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It is preferable in some cases to refer the performance of each of the four oscillators to the mean performance of all four. This is in the event that all four oscillators are equally reliable, in which case the mean of all four makes a better reference standard than the mean of any three. If we designate the numbers

$$1000(f_4-f_1), \quad 1000(f_4-f_2), \quad \text{and} \quad 1000(f_4-f_3)$$

by a, b, and c, respectively, it can be shown readily that the numbers

$$a-\frac{a+b+c}{4}, \quad b-\frac{a+b+c}{4}, \quad c-\frac{a+b+c}{4} \quad \text{and} \quad -\frac{a+b+c}{4} \tag{7}$$

represent the difference between each of the oscillators Nos. 1, 2, 3, and 4, respectively, and the mean of all four, expressed in parts, in

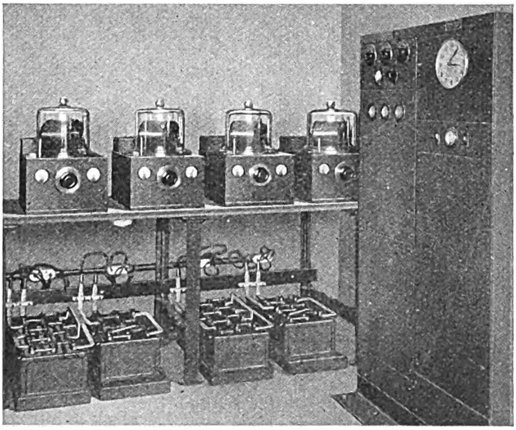

Fig. 17—Four 100,000-Cycle Oscillators With Auxiliary Equipment.

one hundred million. This method treats all four oscillators symmetrically. The symmetry is evident if we substitute in (7) the values (2) assigned to a, b, and c, whence we get:

$$a-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_1\right) \tag{8}$$

$$b-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_2\right) \tag{9}$$

$$c-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_3\right) \tag{10}$$

$$-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_4\right). \tag{11}$$

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The four oscillators used in the equipment described are shown in Fig. 17. The panels on which the controlling and measuring circuits are mounted are at the right of the picture. The 1000-cycle motor-driven clock is at the top of the nearest panel. A schematic of the apparatus showing the general arrangement of parts is given in Fig. 18.

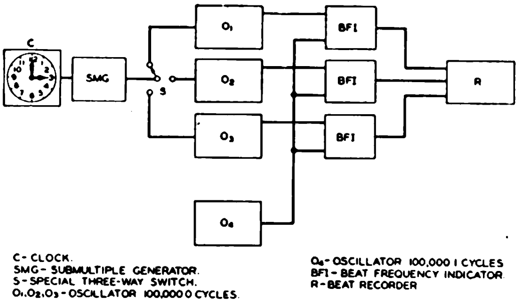

Fig. 18—Schematic of Complete Frequency Standard System.

The circuit of one element of the modulator for producing low-frequency beats is shown in Fig. 19. The input circuits *A* and *B* are supplied from oscillator No. 4 and one of the other three, respectively. The plate circuit includes the windings of a balanced relay which makes a contact once for each cycle difference between the input frequencies at *A* and *B* and which operates the recording mechanism accordingly.

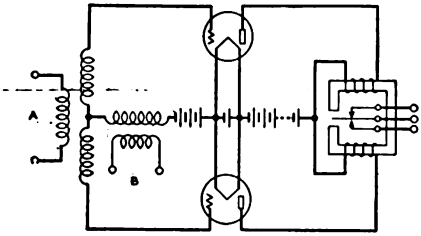

Fig. 19—Balanced Modulator of Beat Frequency Indicator.

The beat recorder is a counter arranged to count these relay operations for a definite time interval, in this case for 1000 seconds, and then to print the total and reset to zero. Five such units are provided which print on a wide strip of paper similar to that used in an adding machine. Three of the counters are used as outlined above. The fourth counter is to be used for recording the mean of these three numbers, computed automatically by an auxiliary device. The remaining one is a serial counter which is used to record the time, either directly or by numbering the 1000-second intervals consecutively.

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The five-element counter is shown in Fig. 20 with the cover removed to show part of the mechanism. The energy for actuating the counting and resetting mechanism is obtained from a small motor run-

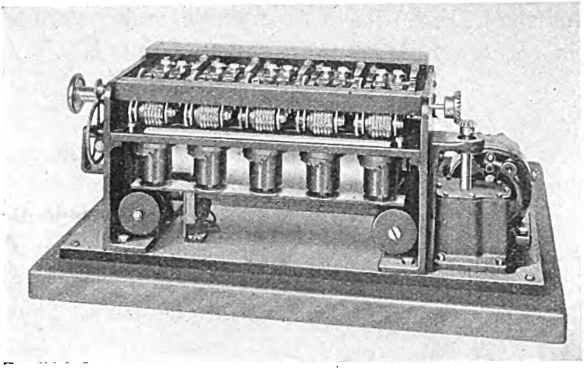

Fig. 20—Automatic Beat Counter.

ning continuously. These elements are operated at the proper times by clutches controlled by electromagnets which are selected by the relays in the modulator circuits described above. The counting, printing, and resetting operations are interlocked by means of cams and relays so

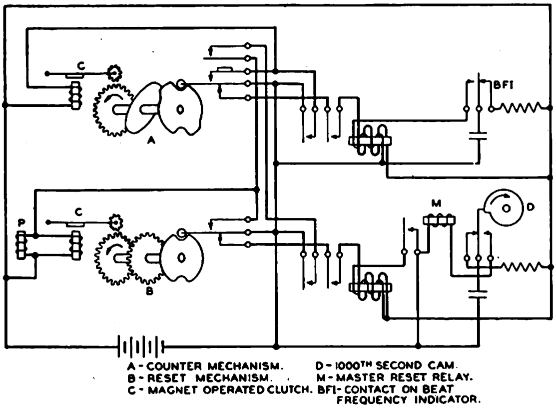

Fig. 21—Electrical Circuit of One Element of Beat Counter.

that no counts may be missed through superposition of operations. The electrical circuit of one unit of the recorder is shown in Fig. 21.

The 1000-second intervals are determined by a cam operated by the 1000-cycle synchronous motor. It might be questioned whether one of the crystals being checked should be used to determine the 1000-

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second intervals. No serious error arises from this, however, since the percentage variation in the interval due to a change in rate of the crystal is only one millionth of the percentage variation in the recorded beat number. Thus, using one crystal to determine the intervals, used in comparing its rate with other crystals, makes the final measurement subject to an error from this cause of only about 0.0001 per cent.

In order to determine extremely small relative variations in frequency between two oscillators a method of measurement is used in which the duration of individual beats between two oscillators may be measured with an accuracy of about one part in 10,000. This is equivalent to saying that the average beat frequency during each 10-second interval is measured with an accuracy of one part in ten thousand. Since the percentage error in the beat frequency is one

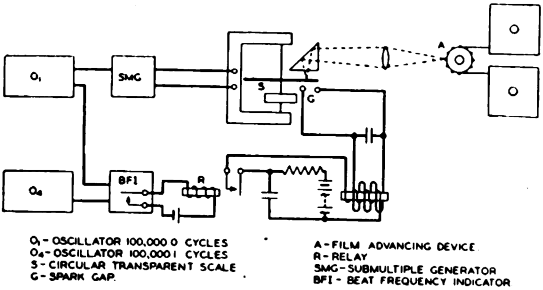

Fig. 22—Circuit of Device for Determining Beat Periods Accurately.

million times greater than the percentage error in the primary frequency, to measure the beat frequency with an accuracy of one part in ten thousand is equivalent to intercomparing the primary frequencies with a precision of one part in ten thousand million. By such a precise method of measurement a great deal can be learned about the nature of the variations that do occur.

The circuit of this device is shown in Fig. 22. Fig. 23 is a photograph of the actual apparatus used in obtaining the data given in Fig. 24. A circular transparent scale S, having 100 numbered divisions, is driven at 10 revolutions per second by a 1000-cycle synchronous motor controlled by one of the crystals. A modulator operates the balanced relay at the difference frequency between the crystal-controlled oscillators. This relay discharges condenser C_1 through the primary in an induction coil, which discharge produces a spark across the gap below the circular scale. The portion of the scale illuminated by the spark is photographed on slowly moving film at A. In this

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manner, assuming a beat frequency of 0.1 cycle per second, 360 checks per hour may be obtained with practically no supervision.

If the sparks occur at exactly an even number of revolutions of the motor apart, the same portion of the scale will be photographed

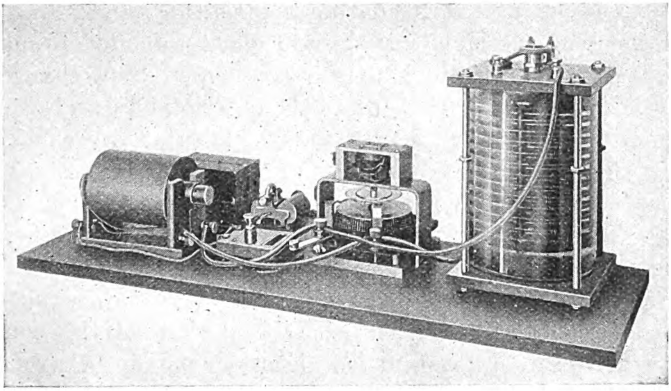

Fig. 23—Apparatus Used for Measuring Beat Periods.

by each spark. If the intervals differ from such a value by 0.001 second, the successive photographic images will differ by one scale division. Thus, the length of the beat periods may be read directly from the photographic records with an accuracy of 0.001 second, which

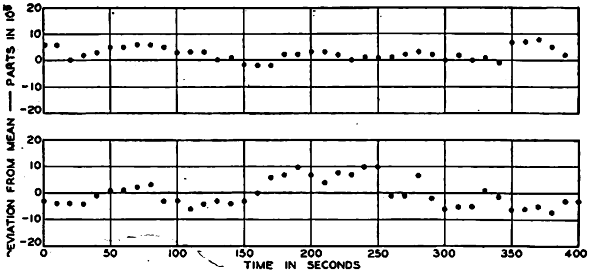

Fig. 24—Relative Rates of Two Pairs of Crystal Oscillators Showing Small Random Variations in Frequency.

determines the length of the 10-second periods with an accuracy of one part in ten thousand. Thus a variation of one division on the photographic record corresponds to a relative variation of one part in ten billion between the two frequencies, compared during an interval only ten seconds long. The whole number of revolutions of the scale may be determined readily by auxiliary means.

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The two graphs in Fig. 24 show typical variations between two crystal oscillators operating under rather unfavorable conditions. One crystal was not in its sealed bell jar and one circuit was only partially shielded and was exposed to draughts of varying temperature. Even under these conditions, however, the variations from the mean did not exceed one part in 10^8 during the test.

The checking methods just described are intended primarily to indicate more or less rapid changes in frequency. Slow changes, and, of course, the absolute rate, can best be determined in terms of standard time. This is done, as previously indicated, by checking the rate of a clock controlled by one of the crystals against radio time signals. Unfortunately no long checks have been obtained as yet in this way, but several tests made over periods of a few days indicate a constancy of rate in the order of 0.01 second a day.

The measurements made so far indicate that the frequency of a crystal-controlled oscillator such as described when suitably controlled, may be expected to be constant to at least one part in 10^7 over periods of seconds or over periods of days. It is hoped that it will be possible in the near future to present accumulated data on the performance of the frequency standard system described.

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OBSERVATIONS ON MODES OF VIBRATION AND TEMPERATURE COEFFICIENTS OF QUARTZ CRYSTAL PLATES*

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Summary—*The characteristics of piezo-electric quartz crystal plates of the perpendicular or Curie cut are compared with parallel or 30-deg. cut plates with reference to the type of vibration of the most active modes, the frequency of these modes as a function of the dimensions, and the magnitude and sign of the temperature coefficients of these frequencies.*

It is pointed out that the two principle modes of the perpendicular cut plate appear to be of the longitudinal type, the high-frequency mode being a function of the thickness while the low-frequency is a function of the width (along the electric axis). Both modes have a negative temperature coefficient of frequency. Of the two corresponding modes of the parallel cut plates, a shear vibration is responsible for the high frequency. This frequency has a positive temperature coefficient. The low-frequency mode is of the longitudinal type and has a negative temperature coefficient.

Considering only the high-frequency vibration of these plates it is observed that there are characteristic variations of the frequency and temperature coefficient with the ratio of dimensions of the plate and the temperature, which are peculiar to the parallel cut plate. These variations can be attributed to a coupling of the shear and longitudinal modes.

It is then shown that if the parallel cut plate be treated as a group of coupled oscillatory systems with appropriate temperature coefficients the usual coupled system analysis will explain the curves of frequency vs. dimensional ratio, frequency vs. temperature, and temperature coefficient vs. dimensional ratio that are characteristic of this plate. This analysis offers an explanation of the low temperature coefficients which can be produced by a proper choice of the dimensional ratios.

WITH the increasing demands of the radio industry for a high degree of carrier frequency stability, considerable attention has been focused recently on the piezo-electric quartz crystal as a circuit element in frequency generating systems. The low damping of these mechanical oscillators, combined with their piezo-electric properties, makes them particularly suitable for frequency control where a high degree of constancy is required. The frequency stability of the quartz plates prepared in the usual manner is, however, often not sufficient for many of the demands for constant frequency. For instance such a crystal plate does not compare favorably as a sub-standard of frequency with a good astronomical clock. To meet the demands for frequency sub-standards as well as many other practical

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problems concerning frequency generation in the communication art, it becomes necessary to devise methods for improving the frequency stability of these crystal systems. This involves a study of the many factors upon which this stability depends.

A crystal plate constitutes an extremely complex vibration system with a large number of degrees of freedom which are for the most part combinations of certain fundamental types of vibration. The ultimate frequency stability attained with a given crystal-controlled frequency generator is then a function of the equivalent electrical characteristics of the combination vibration set up in the crystal plate as well as the constants of the rest of the generator circuit. In particular the frequency change in a crystal oscillator with changes in tube constants or attached load is a function of the equivalent electrical decrement of the vibration which the crystal happens to be executing. Further, the temperature coefficient of frequency of the crystal oscillator depends largely upon the temperature coefficient of frequency of the crystal vibration, which in turn depends upon the change with temperature of the various mechanical elastic constants that are called into play by this vibration.

The general relation between stress and strain, which in an ordinary isotropic medium involves only two constants, in crystal quartz requires six.[1] The choice of a particular constant or constants that enter into a given mode of vibration depends upon the orientation of the plate with respect to the original crystal axes, and the particular type of vibration, whether longitudinal, torsional, etc.

It is to be expected, therefore, that there will be a variation among the characteristics of the modes of vibration of plates cut in a different fashion, as well as between the different modes of a given plate. In practice we have found considerable difference in the magnitude of the electric and electro-thermal constant, between the various modes of vibration of a given crystal plate, even when the vibration frequencies are within a few hundred cycles of each other.

To secure uniformity of results with respect to frequency stability it becomes necessary, therefore, to study the various possible modes of vibration of these crystal plates in detail, and set up certain criteria by which it will be possible to produce plates that will vibrate in a definite mode whose characteristics are known.

The theoretical aspects of this problem offer considerable difficulty, for it will be remembered that the classical case of the vibrations of an isotropic plate whose edges are free has as yet only been solved

[1] Voigt's "Kristallphysik," pp. 749–755, or Love's "Mathematical Theory of Elasticity," Chap. VI.

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approximately[2] and with the extension of the theory made necessary by the crystalline nature of quartz, the complexity of the problem is considerably increased, with the possibility of a complete solution very remote.

Using long rods or bars of crystal, instead of plates, other investigators[3] have been able to set up the three types of vibration (longitudinal, flexural, and torsional) common to isotropic bars. Moreover, the formulas for these vibrations in isotropic material can be used to determine the frequency of the quartz rods to a good first approximation.

Returning to the problem of the plate, if the experimentally determined facts concerning plates of certain definite orientations are examined, it will be seen that they suggest the treatment of the plate as a special case of a bar. A résumé of these facts will illustrate this point and at the same time indicate the effect of orientation on the character of the modes of vibration.

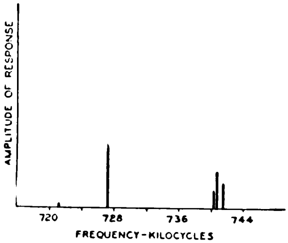

Fig. 1—Showing the response frequencies of 32×47×2.760 mm parallel-cut crystal plate in the region of the major high frequency.

In general, a quartz crystal plate cut with any orientation with respect to the crystal axes will respond to a large number of frequencies. A plot of these frequencies showing their spacing and the relative magnitudes of response[4] may be termed the frequency spectrum of the plate. Fig. 1 shows part of the high-frequency region of such a spectrum. In these frequency spectra there are usually one or more frequencies at which the crystal will react with sufficient voltage to drive a vacuum tube in the usual crystal oscillator circuit.

The relation between these major response frequencies and the dimensions of the plate for the two principal orientations can be outlined as follows:

[2] Rayleigh, "Theory of Sound," Chap. X and X_A.
[3] Cady, Proc. I. R. E. **10**, 83; April, 1922.
Harrison, Proc. I. R. E. **15**, 1040; December, 1927.
Giebe, *Zs. f. Phys.*, **46**, 607, 1928.
[4] The amplitude of response in this case is the maximum amplitude of current through the crystal at constant voltage which in turn is a measure of the equivalent series resonant impedance of the crystal system.

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Curie or Perpendicular Cut

When the crystal plate is so cut that its major surfaces are parallel to the optic axis and perpendicular to an electric axis (the Curie or perpendicular cut, see Fig. 2) there are two principal response frequencies, one high and one low.[5] The high frequency is a function of the thickness of the plate and to a good approximation is given by the expression

$$f=\frac{K}{t} \tag{1}$$

where t is the thickness in millimeters and $K=2.860\times 10^6$.

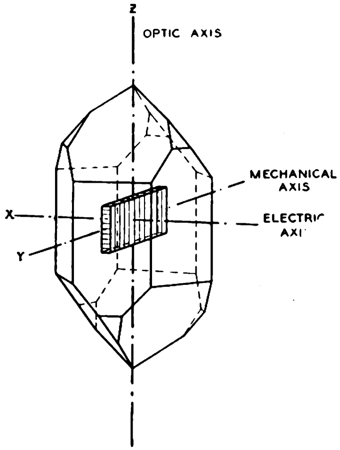

Fig. 2—Showing the orientation of a perpendicular or Curie-cut plate with respect to the crystal axes.

If the plate could be considered as a bar of length t then the frequency of a simple longitudinal vibration would be given by the expression

$$f=\frac{1}{2t}\sqrt{\frac{E_{xy}}{d}} \tag{2}$$

where E_{xy} is Young's Modulus in the X-Y plane and d is the density. If the numerical values[6] of E_{xy} and d are substituted in the above expression it is found that the same value for K is obtained as that of (1).

[5] For this discussion the low-frequency flexural vibration of the type described by Harrison will not be considered.

[6] For numerical values of the elastic constants and the density of quartz see Sosman, "The Properties of Silica," the American Chemical Society Monograph Series, 1928.

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The low frequency is a function of the width, the dimension parallel to the Y axis, and is given by the same expression as (1) with the same value of K, the width in millimeters being substituted for the thickness.

For this type of crystal plate there are then two possible major modes which appear to be of the longitudinal type and depend upon the same elastic constant. (Young's modulus in the X-Y or equatorial plane has the same magnitude in any direction.)

The temperature coefficient of both these frequencies is negative which is in agreement with the temperature coefficient of Young's modulus for the equatorial plane.[7]

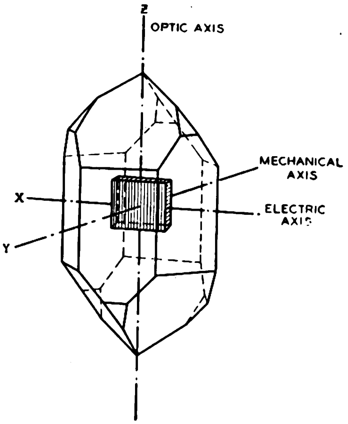

Fig. 3—Showing the orientation of a parallel or 30-deg. cut plate with respect to the crystal axes.

The Parallel or 30-degree Cut

When the crystal plate is so cut that its major surfaces are parallel to both the optic and electric axes (the parallel or 30-deg. cut, see Fig. 3) this 30-deg. shift in orientation from the perpendicular changes the characteristics in some important respects. As before there is a high and a low principal frequency, but in this case the high frequency sometimes occurs as a doublet (two response frequencies a kilocycle or so apart).

For thin plates of large area the high frequency is a function of the thickness of the plate, and is given by the approximate expression

$$f = \frac{K}{t} \tag{3}$$

[7] Perrier and Mandrot, Mem. Soc. Vaudoise Sci. Nat. (1923) 1, 333–364.

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where t is the thickness in millimeters
and K is now 1.96×10^6.
It will be noted that this constant differs from that found in the case of the perpendicular cut crystal. Moreover, the temperature coefficient of this frequency is positive.

These facts lead one to believe that this is not a simple longitudinal vibration. Cady[8] has pointed out that if it be considered as a shear vibration in the X-Y plane the frequency can be calculated using the appropriate shear modulus.[9]

The low frequency is a function of the width, the dimension parallel to the electric or X axis, and is given by the same expression and constant as the frequencies of the perpendicular cut plate. It has the same characteristic negative temperature coefficient.

For these parallel cut plates there are then two possible major modes which, however, differ in type of vibration and sign of temperature coefficient.

Limiting this discussion to the high-frequency region, it is seen that these parallel and perpendicular cut plates have different frequency-thickness constants and temperature coefficients of opposite sign. On closer examination it is found that there is an additional difference which involves the variation of the magnitudes of these frequency thickness constants and temperature coefficients with the ratio of width to thickness of the plate.

For the perpendicular cut plate the frequency-thickness constant changes but little with the size of the crystal. The same is true for the temperature coefficient, and from recent measurements on a number of sizes of plates the magnitude of this coefficient lies between minus 20 and minus 35 cycles in a million per degree centigrade.

The parallel cut plate, on the other hand, has a frequency thickness constant which for any but thin plates of large area varies considerably with the width. The temperature coefficient also varies with the width, and is in addition a function of the temperature. This coefficient has a wide range of values whose limits are approximately plus 100 cycles in a million per degree centigrade and minus 20 cycles in some special instances, with all possible intermediate values including zero. Then, as has been mentioned before, these parallel cut crystals frequently have two high-frequency modes of vibration within a kilocycle or so of each other and will start on either of these modes if the circuit con-

[8] W. G. Cady, *Phys. Rev.*, 29, 617, 1927.

[9] If it could be shown that the shear modulus of this plane had a positive temperature coefficient it would substantiate this assumption, but there is no information at present available regarding the effect of temperature on the elastic constants other than for the two values of Young's modulus.

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stants are changed slightly. These two modes usually have widely different characteristics.

Apart from this seemingly erratic variation it has been the experience of this laboratory that the parallel cut crystal will oscillate more readily in the Pierce type of oscillator circuit. For this reason this type of crystal has been used for a number of purposes and these observed variations have been the object of considerable study.

As a result of this work an explanation has been evolved to account for these variations. This explanation not only suggests reasons for the above mentioned phenomena, but what is more important, it indicates the procedure by which it is actually possible to produce crystals having negligible temperature coefficients. Before outlining this theory the experimental facts which served as its foundation will be discussed in detail.

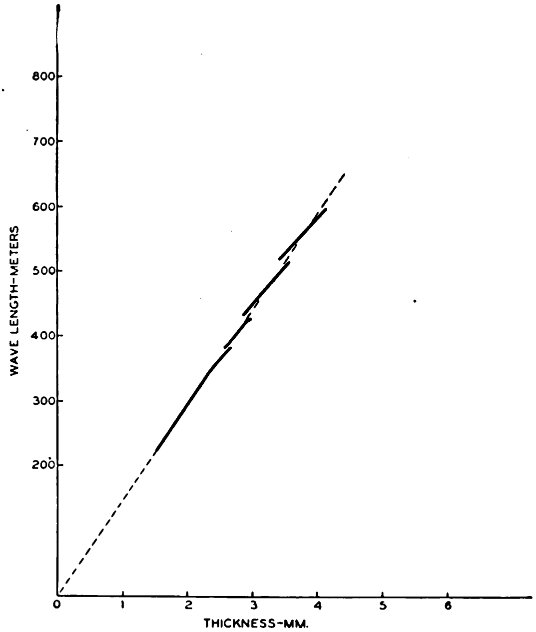

Fig. 4—The wavelength at which a 2.5-cm square parallel-cut crystal plate will operate, in an oscillator circuit, as its thickness is progressively reduced.

Frequency-Thickness Constant as a Function of Dimensions

When work on the production of parallel cut crystals in the broadcast frequency band was first started, it was found that it was very difficult to grind crystals for certain low frequencies using a 2.5-cm

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square plate because of discrete jumps in frequency for a small reduction of thickness. Fig. 4 is a typical curve showing the wavelength[10] as a function of the thickness for a 2.5-cm square crystal. This curve should be a straight line (for from equation (3) it is evident that $\lambda = K't$) but it will be noted that there are certain discontinuities at the upper end. It was found that these discontinuities were present at frequencies that could be identified with harmonics of the frequency which the crystal would have if it were vibrating in the direction of its length along the electric axis.

This was the first definite indication obtained in these laboratories that the longitudinal vibration of the crystal in the direction transverse to the applied field could affect the frequency supposed to depend only on the thickness. It was checked by further work on crystals of other dimensions, and in each case the position of these discontinuities was found to depend on the width of the crystal.

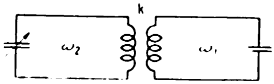

Fig. 5

The presence of a resonant system whose frequency depends upon the width is evidently responsible for this phenomenon, this system affecting the frequency of the vibration along the thickness through some form of mechanical coupling. At the suggestion of R. A. Heising of the Bell Telephone Laboratories, an explanation of these experimental facts was developed based on the treatment of the plate as a system of coupled circuits.[11] Consider the two coupled oscillatory circuits shown in Fig. 5, having the uncoupled radian frequencies ω_1 and ω_2, then the frequencies of the coupled system in the absence of damping will be given by the usual expression[12]

$$\omega = \frac{\sqrt{\frac{1}{2}(\omega_1^2+\omega_2^2) \pm \frac{1}{2}\sqrt{(\omega_1^2-\omega_2^2)+4k^2\omega_1^2\omega_2^2}}}{\sqrt{1-k^2}} \tag{4}$$

k being the coupling.

If these two frequencies be plotted as a function of the tuning of the second circuit, i.e., ω_2, the familiar set of curves shown in Fig. 6 results.

[10] In plotting the change in rate of vibration of a crystal plate as a function of the dimensions it is more convenient to use wavelength instead of frequency because of the direct linear relation between the dimensions and the wavelength.

[11] The term "circuit" is introduced here to describe a mechanical oscillatory system because many readers are accustomed to think in terms of electrical circuits.

[12] See Pierce, "Elec. Osc. and Waves," Chap. VII.

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Suppose now other circuits are added to the system as shown in Fig. 7, each additional circuit being fixed at a harmonic of the uncoupled frequency of circuit No. 2, and so linked with this circuit mechanically that the group is tuned as a whole.

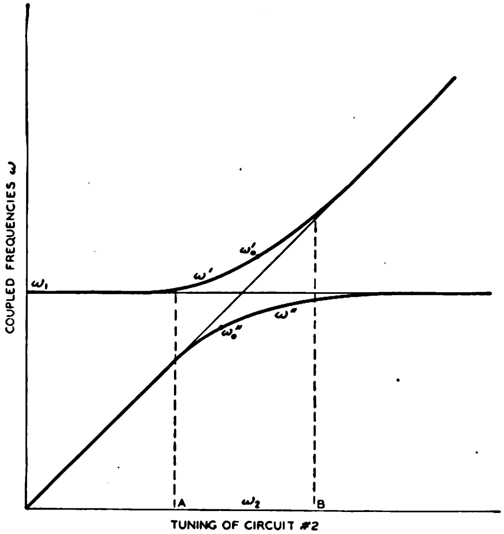

Fig. 6—Showing the radian frequencies of a system of two coupled circuits as a function of the tuning of one circuit, the tuning of the other circuit being fixed.

There are now two possible combinations depending upon which circuit or group of circuits is kept fixed while the other is varied. If the case in which the second group of circuits is kept fixed be examined first, it will be seen that as the frequency of circuit No. 1 is varied, it

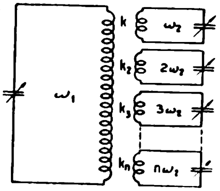

Fig. 7

will come into tune successively with each of the circuits of the second group. The result will be a series of coupling curves with the characteristic reaction illustrated by Fig. 6 repeated at each coincident point. If it be assumed that the coupling decreases as the order of the harmonic increases, then the magnitude of the reaction also decreases. This

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is illustrated by Fig. 8 which shows the coupling curves of such a system plotted in terms of the equivalent electrical wavelength.

Returning to the crystal plate, if the vibration in the direction of the thickness be identified with circuit No. 1 while the width vibration and its harmonics be identified with circuit group No. 2, then Fig. 8 should represent what happens to the crystal wavelength as the thickness is reduced. Comparing Figs. 4 and 8 it is seen that this is true in a restricted region but that the wavelengths which depend upon the width vibration do not continue much beyond the coupling region in the experimental curves. This is to be expected, for these wavelengths-

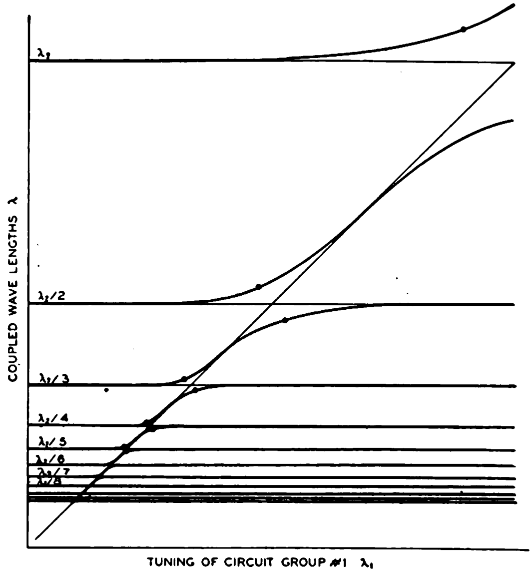

Fig. 8—Showing the wavelengths of the system of coupled circuits of Fig. 7 as a function of the tuning of circuit No. 1, the tuning of circuit group No. 2 being fixed.

which depend upon a harmonic of a vibration transverse to the ap, plied field, are more difficult to excite than the fundamental in the direction of the field. This particular point is discussed further in connection with temperature coefficients.

If now the case be examined in which the tuning of the second group of circuits is varied, it will be seen that the coupling curves are slightly different in character. The curves for this case are illustrated by Fig. 9, which shows the wavelengths of this system as a function of the tuning of circuit group No. 2. Fig. 10 shows the wavelengths at which a parallel cut plate will oscillate plotted as a function of the width. The similarity between this experimentally determined curve

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and Fig. 9 is at once apparent. There is one anomalous segment of a curve between the 7th and 8th harmonics, the line AB; but it is possible that this is caused by the coupling of some third free period which has not been considered, perhaps a high order harmonic of a flexural vibration. In general, however, the curves of wavelength versus width or wavelength versus thickness for these crystal plates are of such a character as to indicate that the analogy between the two systems of coupled circuits and the crystal modes of vibration is sufficiently good to serve as a useful guide.

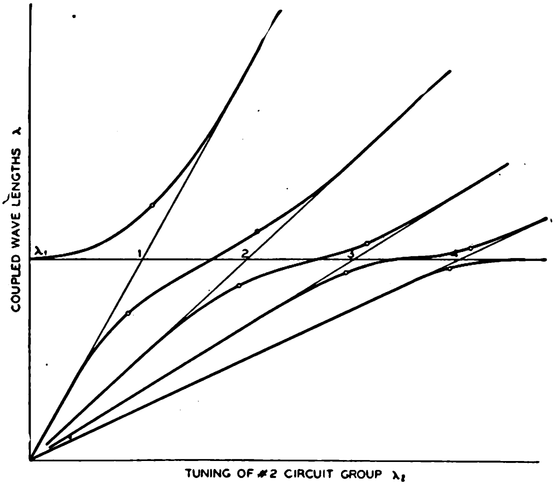

Fig. 9—Showing the wavelengths of the system of coupled circuits of Fig. 7 as a function of the tuning of circuit group No. 2, the tuning of circuit No. 1 being fixed.

If, then, these parallel cut crystal plates are considered as a system of coupled circuits the reason for the variation of the frequency thickness constant with dimensional ratios and the presence of the frequency doublets is at once apparent. With the coupling at the various harmonics determined, the character of these variations can be predicted. Given an experimentally determined series of coupling curves similar to Fig. 10, the coupling at the nth harmonic can be determined from the expression

$$k_n = \frac{\left(\frac{\lambda'}{\lambda''}\right)^2 - 1}{\left(\frac{\lambda'}{\lambda''}\right)^2 + 1} \tag{5}$$

where λ' and λ'' are the wavelengths of the coupled system at the point where $\lambda_1 = n\lambda_2$.

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Temperature Coefficient as Function of Dimensions and Temperature

As mentioned above, when the temperature coefficients of these parallel cut crystals were studied it was found that there was considerable variation between plates having the same thickness but slightly different areas, and the temperature coefficient of a given plate was found to be a function of the temperature. To illustrate this last point a typical frequency-temperature curve for a parallel cut crystal is shown in Fig. 11. It will be noted that the frequency increase is linear until a given temperature is reached, at which point the curve flat-

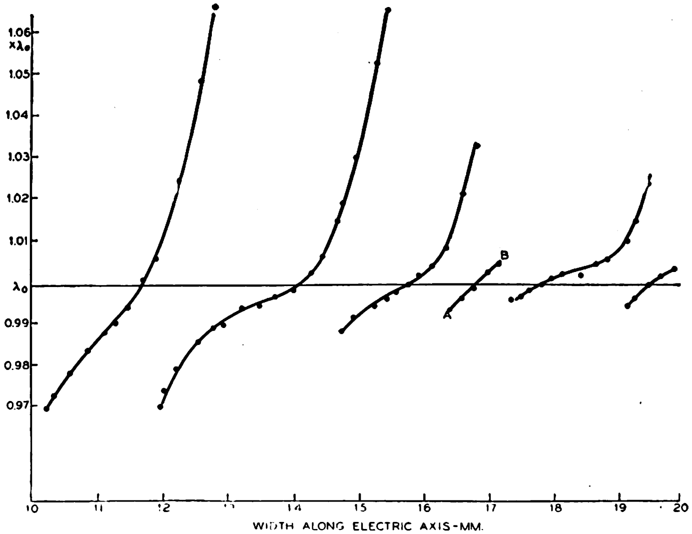

Fig. 10—The wavelengths at which a parallel-cut crystal will operate in an oscillator circuit as its width (the dimension along the electric axis) is progressively reduced. The other dimensions are fixed. $\lambda_0 = 153 \times$ thickness.
Thickness along mechanical axis = 1.64 mm
Length along optic axis = 54.8 mm

tens off and then begins to reverse. Just beyond the point of reversal the frequency jumps to a new value, and if the curve is continued the frequency increases again at the same rate as originally. This type of frequency-temperature curve is common to a large percentage of parallel cut crystals, the only difference being the width of the flat part of the curve and the temperature at which the discontinuity occurs.

W. A. Marrison of the Bell Telephone Laboratories first suggested that low temperature coefficients could be obtained with parallel cut crystals by utilizing the coupling of two modes of vibration having

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individual coefficients of opposite sign. Several of this type of low temperature coefficient crystal were produced by Marrison and are described in his concurrent paper, "A High Precision Standard of Frequency."

If Heising's coupled circuit analysis is extended to include the effect of temperature, and if the proper temperature coefficients with due regard to relative magnitude and sign are identified with each circuit, the change in temperature coefficient with dimensional ratio and

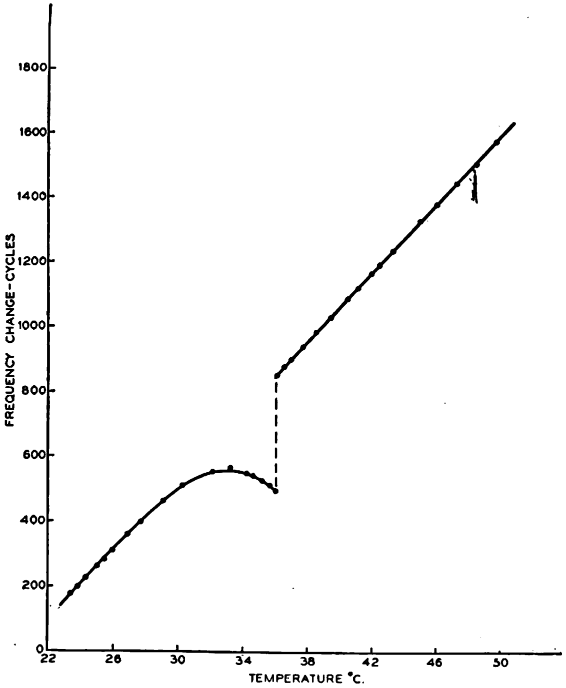

Fig. 11—The frequency change of a 32×47×2.760 mm parallel-cut crystal with temperature.

temperature can be explained. In addition, the relative value of the tuning of the oscillatory circuits or, in terms of the crystal plate, the dimensional ratios which yield zero temperature coefficients for a given temperature can be predicted if the coupling is known.

Referring again to Figs. 5 and 6, suppose the two coupled circuits have temperature coefficients of opposite sign, circuit No. 1 being positive and circuit No. 2 negative, then for ω_2 less than ω_1 say at the point A, Fig. 6. ω' has a positive and ω'' a negative temperature coefficient. For a value of ω_2 greater than ω_1 say at B, ω' now has a negative and ω'' a positive temperature coefficient, ω' and ω'' having

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interchanged roles. Somewhere between, therefore, both ω' and ω'' must have had a zero temperature coefficient. Returning to (4), if this expression for ω be differentiated with respect to the temperature, regarding k, the coupling, as constant, and the result placed equal to zero, the condition that ω is independent of temperature[13] is obtained as follows:

$$\omega^2 = \frac{\omega_1{}^2\omega_2{}^2(m-n)}{(m\omega_1{}^2 - n\omega_2{}^2)} \tag{6}$$

where $m = (1/\omega_1)(d\omega_1/dT)$ = temperature coefficient of circuit No. 1
$n = -(1/\omega_2)(d\omega_2/dT)$ = temperature coefficient of circuit No. 2.
Now let $Q = n/m$; then (6) becomes

$$\omega^2 = \omega_2{}^2 \frac{1-Q}{1-Q\left(\dfrac{\omega_2}{\omega_1}\right)^2} \tag{7}$$

Solving (7) for ω_2/ω_1 and replacing ω^2 by its value from (4) we obtain

$$\left(\frac{\omega_2}{\omega_1}\right)^2 = \frac{k^2(1-Q)^2}{2Q} + 1 \pm \sqrt{\left[\frac{k^2(1-Q)^2}{2Q}\right]^2 + \frac{k^2(1-Q)^2}{Q}}$$

which when k is small becomes

$$\left(\frac{\omega_2}{\omega_1}\right)^2 = 1 \pm \frac{k(1-Q)}{\sqrt{Q}}\,. \tag{8}$$

This equation gives the tuning points, or the values of ω_2, at which the radian frequencies of the coupled system, ω' and ω'', will have zero temperature coefficients, in terms of the ratios of the uncoupled temperature coefficients and the coupling.

Referring again to Fig. 6, ω_0' and ω_0'' represent the values of ω' and ω'' which have zero temperature coefficient provided that m is greater than n, that is, the temperature coefficient of ω_1 is greater in magnitude than that of ω_2. Carrying this idea over to the case of the group of circuits for which the curves of Figs. 8 and 9 are drawn, there will be points of zero coefficient in the neighborhood of each coupling point as indicated by the circles on the curves.

The above conditions for zero temperature coefficient apply only if the coefficient as a function of the tuning be considered in the region of some given temperature. If the temperature is varied over a consider-

[13] F. B. Llewellyn of the Bell Telephone Laboratories is responsible for this analysis.

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able range, a small change in the tuning of both circuits is effected, one having its frequency raised, the other lowered. The result of this tuning on the frequencies of the coupled system can be illustrated by Fig. 12, which shows the tuning with temperature on a magnified scale. In this figure the lines ω_1 and ω_2 represent the change in frequency of these circuits with temperature if there were no coupling between them. The change in the frequencies of the coupled system with temperature is shown by the curves ω' and ω''. It will be seen that both these frequencies pass through regions of zero temperature coefficient.

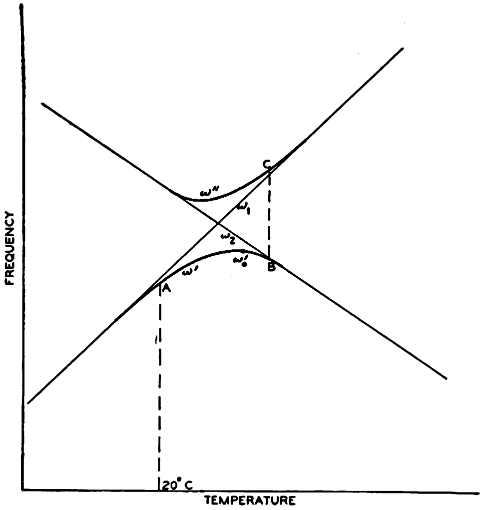

Fig. 12—Effect of temperature on the radian frequencies of a system of two coupled circuits having temperature coefficients of opposite sign.

Such frequency-temperature curves can be derived graphically by a construction similar to that shown in Fig. 13. This figure illustrates what happens when the tuning of both circuits No. 1 and No. 2 is varied, and consists of a series of the usual coupling curves (the coupled frequencies plotted as a function of ω_2) each set of curves of the series being drawn for a different value of ω_1. When the temperature is increased from T_1 to T_2 the uncoupled frequency of circuit No. 2 is reduced by an amount $\Delta\omega_2$ and the uncoupled frequency of circuit No. 1 is increased by an amount $\Delta\omega_1$. The result is that the frequencies ω' and ω'' move from curve to curve in the direction shown by the lines AB and CD.

If now the variation of the temperature coefficient of a crystal plate when used in an oscillator circuit be examined at a given temperature as the width is changed (which amounts to a change in the

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tuning of the transverse vibration) it will be seen that the experimental results are in accord with the above treatment. Fig. 14 shows the temperature coefficient of the two frequencies of a crystal plate at 58 deg. C as its width is progressively reduced in the neighborhood

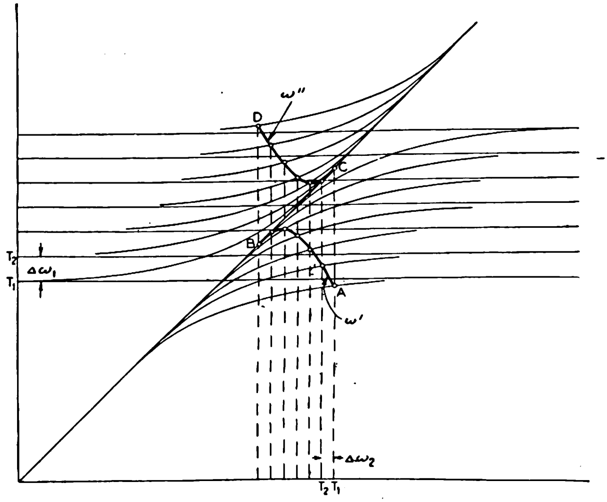

Fig. 13—Effect on the radian frequencies of a system of two coupled circuits as the individual circuits are tuned simultaneously in opposite directions.

of the 5th harmonic of the transverse vibration. These curves show how the temperature coefficients change sign in this region. The dotted sections of the curves are extrapolated, for owing to the rapid reduction in activity once a coupled frequency acquires a negative

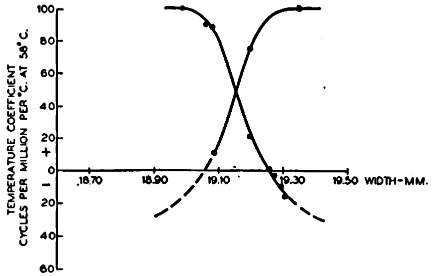

Fig. 14—The change of temperature coefficient of a parallel-cut crystal at 58 deg. C as the width is progressively reduced in the region where the fifth harmonic of the vibration in the direction of the width coincides with the frequency of the vibration in the direction of the thickness.

coefficient, data on the crystal plate used as an oscillator are difficult to obtain in this region.

Returning to the experimentally determined curve of frequency versus temperature for a parallel cut crystal plate shown in Fig. 11,

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this can also be explained with the aid of the above analysis. Referring to Fig. 12, if it be assumed that at 20 deg. C the crystal is oscillating with a frequency A, this is in the region where this particular frequency has a positive temperature coefficient. As the temperature increases the frequency increases in the direction of B, passing through a maximum at the point ω_0' where it has zero coefficient, and then decreases. As the frequency decreases the activity of this particular mode decreases rapidly and finally the crystal frequency hops to point

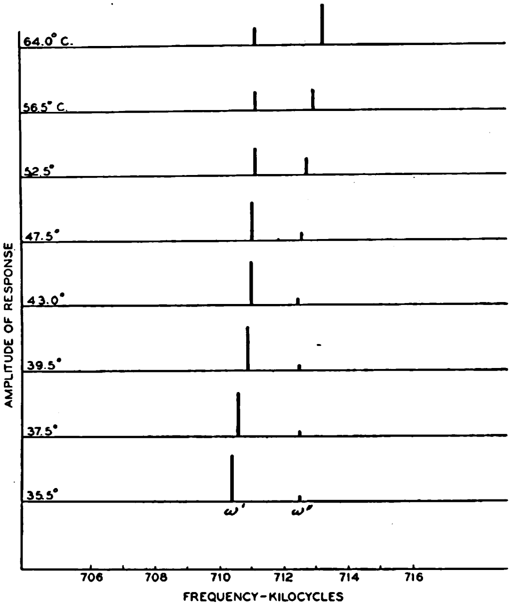

Fig. 15—The response frequency spectra of a parallel-cut crystal plate at different temperatures illustrating the interchange of activity between the two frequencies as the frequencies of the two modes of vibration pass through a coincident value.
Length of plate along optic (Z) axis = 47 mm
Width along electric (X) axis = 19.35 mm
Thickness along mechanical (Y) axis = 2.75 mm

C on the ω'' curve. From this point on the frequency increases with temperature, for this frequency has a positive temperature coefficient in this region.

If it were not for the decrease in activity of the period with the negative temperature coefficient it would be expected that the crystal frequency, instead of "hopping" would continue to decrease with increase in temperature. In some instances (for low order of harmonics) the crystal frequency will decrease for a few degrees, and it is found that the magnitude of the negative coefficient for this region approxi-

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mates that to be expected for the transverse vibration alone. In general, however, a frequency jump occurs just after the zero temperature coefficient region is passed.

This interchange of activity of these two periods as they interchange temperature coefficients can be studied in detail by examining the changes in the spectrum of a crystal at different temperature levels. Fig. 15 shows a series of spectra of a crystal taken for different tem-

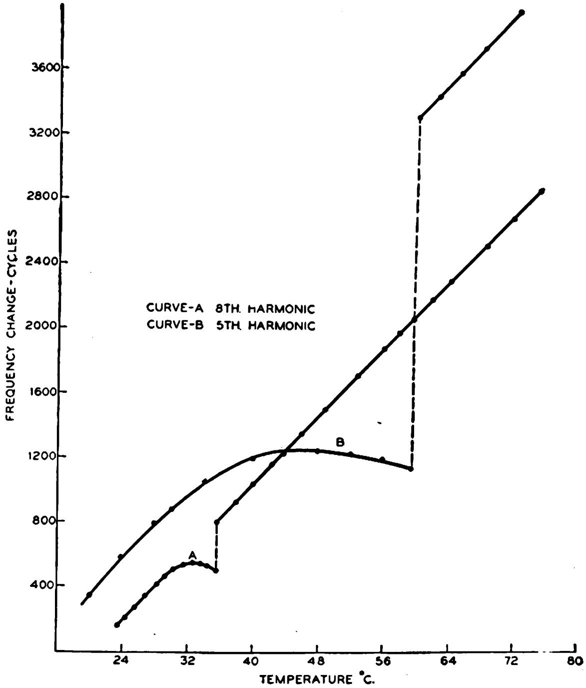

Fig. 16—The frequency change with temperature of two parallel-cut crystals of different width.
Curve *A* region of eighth harmonic (width = 32.0 mm)
Curve *B* region of fifth harmonic (width = 19.35 mm)
Both plates[14] have a length of 47 mm and a thickness of 2.75 mm.

peratures in the region of zero temperature ceofficient, the dimensions of the crystal being unchanged. These spectra illustrate the rapid decrease in activity of the frequency ω' after it passes through zero temperature coefficient while at the same time ω'' increases and assumes the place of major activity vacated by ω'.

[14] The information represented in Figs. 11, 14, and 16 was obtained from four different crystal plates of a group which were exactly similar with respect to orientation and original dimensions.

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The assumption that the coupling increases with the decrease in the order of the harmonic finds confirmation in the experimentally determined facts as computed from curves of the type shown by Fig. 10. As the coupling increases the temperature range for which there is no frequency change with temperature increases, that is, the region of zero temperature coefficient becomes extended. To illustrate this, Fig. 16 shows two curves of frequency versus temperature, one for the coupling of a 5th harmonic, the other for an 8th.

It would, of course, be desirable to extend the zero temperature coefficient range over the limits of temperature to be expected in normal operation. This necessitates tight coupling of the two modes which in turn demands a dimensional ratio in the neighborhood of unity. The cross sectional area of such a plate in the direction of its thickness and width approaches a square in shape which, for high-frequency crystals, is of very small dimensions.

Before concluding it should be noticed that since both modes of the perpendicular cut crystals have a negative temperature coefficient it is to be expected that it would be impossible to obtain zero temperature coefficient crystals with this orientation. This seems to be true as far as our experience with those crystals is concerned.

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THE KYLE CONDENSER LOUD SPEAKER*

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Summary—*By using the Kyle principle of construction, it has been possible to develop a practicable condenser loud speaker. The Kyle construction uses a flexible dielectric diaphragm in contact with the high points of a rigid, undulated metal plate. The electrodes of the condenser are the rigid plate and a flexible metal layer attached to the opposite surface of the dielectric. A comparatively large actuating force is thereby obtained and at the same time sufficient amplitude of motion is permitted to give efficient and faithful reproduction.*

I. Introduction

By electrical means it is possible to produce a mechanical force in one of two ways, magnetically or electrostatically. In most practicable loud speakers up to a recent date only magnetic forces have been used. It has long been recognized that an electrostatic loud speaker is theoretically possible, but numerous attempts to design one have met with indifferent success. The fundamental difficulty seems to have been that in order to obtain sufficient attractive forces, electrode separations have had to be so small that the device was impracticable to construct, and that the small separations did not permit sufficient amplitude of motion.

However, a way of surmounting this difficulty has been shown by Colin Kyle[1] and a loud speaker has been designed on the Kyle principle which gives very satisfactory performance.

This paper will present some of the theoretical considerations involved in the design of the Kyle type of speaker, together with a brief discussion of the practical problems met with in its design and application.

II. Theoretical

a. Electrostatic Attraction in a Condenser.

Considering an electrical condenser formed by two flat parallel plates with the space between the plates partly filled by a slab of dielectric material of thickness t and dielectric constant K, and the remainder of the space filled by air, the force between the plates is given by

$$F = \frac{AV^2}{8\pi\{h - t(1 - 1/)K\}^2} \tag{1}$$

* Dewey decimal classification: R376.3. Original manuscript received by the Institute, April 9, 1929.

[1] U. S. Patent No. 1,644,387

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where A = area of plates, V = potential difference between the plates, and h = distance between the plates.

As h approaches t, the force will approach F_1 which is given by

$$F_1 = \frac{AV^2K^2}{8\pi t^2}. \tag{2}$$

If the relationship between h and t is given by $h = nt$, (1) will reduce to (3)

$$F_n = F_1 \frac{1}{\{1+(n-1)K\}^2}. \tag{3}$$

In Fig. 1 is presented graphically the computations from (3) for three values of dielectric constant. The curves show that the force between the plates falls off very rapidly as the thickness of the air layer increases relatively to that of the dielectric slab.

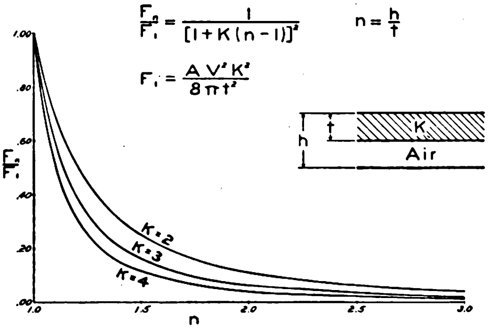

Fig. 1—Variation of Force between Condenser Plates with Relative Thickness of Air Film.

b. Action of Kyle Reproducer.

The Kyle reproducer is shown diagrammatically in Fig. 2. It consists essentially of a perforated metal back plate *a* having corrugations or other undulated surface, a flexible dielectric diaphragm *b* stretched over this back plate so as to bridge across the depressions, and a thin flexible conducting coating *c* cemented or otherwise secured to the surface of the diaphragm opposite the back plate.

As illustrated in Fig. 1, the attractive force is largely confined to a narrow zone adjacent to the contact point, and in this zone it may be comparatively large if the dielectric is thin and K is not too small.

As the diaphragm is attracted under the influence of the electrostatic force, the area of contact is increased and the diaphragm rolls down the slopes of the depressions. The air space is still wedge-shaped

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near the point of contact so the attracted area moves down the slope also. The reproducer owes its efficiency to the fact that we have this wedge-shaped air space which permits a large force to be exerted and at the same time allows a large amplitude to motion.

c. The Biasing Voltage.

As shown above, the attraction between the back plate and flexible diaphragm may be expressed in the form

$$F = MV^2 \tag{4}$$

where M is a constant and V is the potential difference between the plates. This is a law of force which is analogous to the law in the magnetic telephone receiver and the thermophone, and so it appears that a permanent biasing potential is required in the condenser speaker just as a permanent magnetic field is required in the magnetic receiver and as a d-c heating current is required in the thermophone.

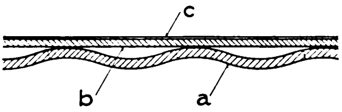

Fig. 2—Cross Section of Kyle Speaker.

To illustrate we shall take the case of an applied direct voltage and two alternating voltages. The force acting between the plates is then given by (5)

$$F = M(V_0 + V_1 \cos pt + V_2 \cos qt)^2 \tag{5}$$

V_0 being the direct voltage, V_1 and V_2 being the maximum values of the alternating voltages, p and q being their respective angular veloccities. Expanding (5) we get,

$$\left.\begin{aligned} F = M(V_0^2 + \tfrac{1}{2}V_1^2 + \tfrac{1}{2}V_2^2) \quad & \text{(a)} \\ + M(\tfrac{1}{2}V_1^2 \cos 2pt + \tfrac{1}{2}V_2^2 \cos 2qt) \quad & \text{(b)} \\ + M(V_1V_2 \cos [p+q]t + V_1V_2 \cos [p-q]t) \quad & \text{(c)} \\ + M(2V_0V_1 \cos pt + 2V_0V_2 \cos qt). \quad & \text{(d)} \end{aligned}\right\} \tag{6}$$

Part (a) represents a steady component of the force which draws the diaphragm away from its neutral position but does not contribute to the sound.

Part (b) represents alternating components of the force with frequencies double those of the impressed alternating voltages and which therefore introduce double frequency distortion into the sound.

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Part (c) represents alternating components of the force with frequencies which consist of sums and differences of the incoming frequencies considered in pairs, and which introduce the corresponding distortion into the sound.

Part (d) represents the alternating components of the force which correspond to the impressed voltages and which produce the desired sound.

Consideration of the coefficients of the terms in (b) and (c) as compared with (d) shows that the predominance of the desired sound represented by (d) over the undesired sound from (b) and (c) depends on the predominance of V_0 over V_1 and V_2. If V_0 is large compared with V_1 and V_2, then $2\,V_0V_1$, and $2\,V_0V_2$ are large compared with $V_1\ V_2$, $\frac{1}{2}V_1^2$ and $\frac{1}{2}V_2^2$. In other words, the correct biasing voltage V_0 must be large compared to the amplitudes of the alternating voltages in order that the resulting sound wave forms may be a reasonably good representation of the wave forms of the alternating voltages.

Since the coefficients in (d) contain V_0 as a factor, the efficiency as well as the tone quality depends on V_0. With a given amplitude of alternating voltage the amplitude of the force varies directly with V_0 and the energy output varies directly with V_0^2.

d. Operating Characteristics of the Kyle Speaker.

Frequency response curves of these speakers taken with a constant alternating voltage applied between the plates show the following characteristics. The response is practically flat between 100 and 1000 cycles. Above 1000 cycles there is a strong rising tendency, the curve reaching a maximum at about 5000, above which it drops very slowly, retaining a considerable intensity at 10,000. There is practically a total absence of peaks and irregularities in the curve.

We have in the wave emitted from this speaker a condition which is seldom met with in acoustic devices. The different parts of the radiating area move independently and accurately in phase so that in the case of the flat speaker the result is the emission of practically a perfect plane wave at all frequencies. Very interesting diffraction effects are observed when the speaker is operated in a deadened room. There is a well defined interference pattern and a marked dependence upon frequency of the divergence of the sound beam. These effects are, of course, not particularly noticeable in the ordinary room but they make it difficult to obtain a single response curve which adequately represents the preformance of the speaker.

The above description of the characteristic was derived from consideration of curves taken at a large number of positions and weighted mentally.

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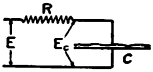
The performance of this type of speaker, as of any other type, is influenced by the characteristics of the circuit in which it is used. Being a voltage operated device, anything which affects the voltage appearing across the plates will have the corresponding effect on the response. A satisfactory approximate analysis of the circuits may be made by considering the impedance of the condenser speaker as being due only to its static capacity. The experiments bear out the fact that this component of the impedance is the predominating one.

An example of this analysis is illustrated in Fig. 3. The circuit shown is approximately the equivalent, as far as the a-c characteristics are concerned, to the output circuit of a vacuum-tube choke coupled to a condenser speaker. The graph shows the variation with frequency



$$\frac{E_c}{E} = \frac{1}{\sqrt{\omega^2 R^2 C^2 + 1}} \qquad \omega = 2\pi f$$

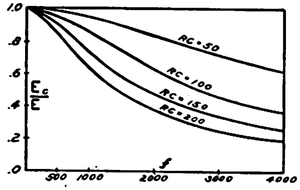


Fig. 3—Voltage Division between Condenser and Resistance.

of the voltage appearing across the condenser. It is therefore seen that if we measure the response of a condenser speaker maintaining a constant voltage across it, giving the response curve described above, the response in the circuit shown may be obtained by multiplying the ordinates by the ordinates of the proper curve of Fig. 3. The fact that the speaker has a rising characteristic makes it possible by choosing the proper value of *RC* to match it into the circuit so as to give almost a perfectly flat response over practically all of the useful part of the audible range.

III. Practical Design

a. The Back Plate

An extensive series of experiments has led to the form of back plate which is being used at present. In order to reproduce successfully low-frequency sounds it is necessary to have a considerable portion of the diaphragm moving with a considerable amplitude. On the other

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hand, the force on the diaphragm depends on the length of the wedge shaped air spaces which increases with the number of points of contact. The present design is a compromise in which the greatest linear contact length is used which will permit of satisfactory frequency response. It has been empirically determined that for the kind of diaphragm material used the best compromise is effected when the back plate is corrugated with a shallow wave 0.012 in. deep and 3/4 in. from crest to crest. The design of the plates depends also to some extent on the biasing voltage to be used. The present plate has been designed to use from 500 to 600 volts as it has been found that voltages of this order are necessary to procure satisfactory efficiency and tone purity.

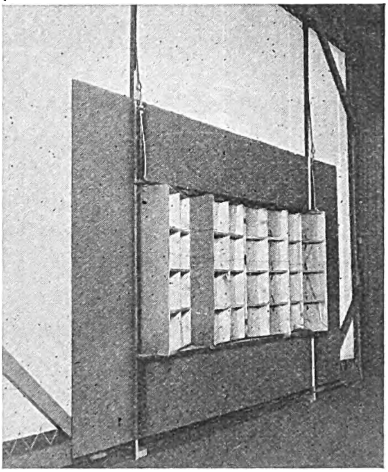

Fig. 3a—48-Section Speaker for Sound Pictures.

In order to procure freedom of motion of the diaphragm it is necessary that the back plate be perforated to permit free passage of the air in and out of the space between it and the diaphragm. A slot has been determined which satisfactorily vents the plate without reducing the area too greatly and which reduces excessive viscous resistance to the air movement. To insure that the diaphragm remain in close contact with the crests of the corrugations the plate is made slightly convex toward the diaphragm.

The back plate should be made of fairly thick metal to give as much stiffness as possible. The kind of metal is not so important being chiefly governed by cost considerations and the necessity for avoiding corrosion.

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The speakers are at present being made in self contained units of 8 in. by 12 in. size. This plan offers flexibility in their use, as various sizes and shapes of speakers can be built up from these units.

b. The Dielectric.

Referring to (2) it is seen that in order to get the largest force the dielectric must be as thin as possible and have a high dielectric constant. However, in order to obtain sufficient dielectric strength and also to remain within manufacturing limits it is hardly practicable to use thicknesses below 0.005 in. or 0.004 in., in the materials which have proven to be satisfactory. To obtain a sufficient margin of safety it is desirable that the dielectric strength be at least 2000 volts. The speakers are tested at this voltage in order to discover any weak spots or pin holes. There is not much freedom of choice in the matter of dielectric constant and so far the material has been used which has satisfactory properties in other respects.

It is absolutely necessary that the diaphragm material possess a degree of flexibility approximately equal to that of rubber dam. Additional stiffness seriously affects the freedom of motion, especially at low frequencies.

The material must not deteriorate rapidly with respect to its dielectric strength and flexibility. A life of three or four years is perhaps the minimum that may be permitted.

A special rubber compound called Kylite has been developed giving these desired properties.

c. The Metal Coating.

The metal coating on the front surface of the diaphragm must be sufficiently flexible so that no appreciable stiffness is added to the diaphragm. Beaten leaf is perhaps the most satisfactory material so far tried. If a leaf or foil is used it must be not much thicker than 0.0001 in. and preferably thinner.

IV. Application

a. Mounting.

The performance of any loud speaker is improved by use of an appropriate baffle. The Kyle speaker requires less additional baffle than a small cone because its own area acts as a partial baffle. To reproduce satisfactorily the lowest frequencies of which the speaker is capable it is desirable to have a baffle which adds a margin of at least 10 in. around the edge of the reproducing unit. This may be in the form of a rectangular box or flat, as shown in Fig. 4.

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It is necessary that considerable freedom be left behind the speaker for movement of the air. The rear should not approach closer than 6 in. to a solid wall, but the space back of the sections can be utilized for a radio set and power pack provided that they do not fill up the area too solidly. For the speaker sections to be used most effectively they should all be in approximately the same plane, the plane facing the normal position of the listener.

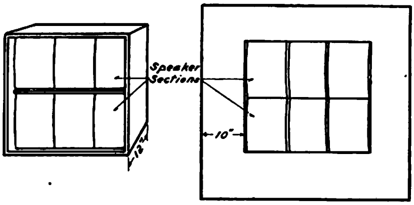

Fig. 4—Kyle Speaker Baffles.

Care must of course be taken that nothing in the baffle or speaker mounting resonates appreciably with a natural period in the audible frequency range. An exceptionally objectionable resonance comes in occasionally if a large area Kyle speaker is solidly supported all around its periphery. In this case the whole speaker itself is likely to vibrate as a diaphragm and attain sufficient amplitude to cause the Kylite to be thrown away from the back plate and produce a buzzing sound. The remedy for this condition is to divide the speaker by a stiffening member or to use braces attached to the center of the speaker.

b. Circuits.

As ordinarily hooked up, the circuit using the condenser speaker may be considered equivalent to that of Fig. 3, where R is the output impedance of the amplifier and a constant input voltage E is being applied. The capacity C of the speaker averages about 0.004 μf per 8 in. by 12 in. section. Referring to the curves of Fig. 3 it is seen that we can alter the frequency response of the combination by changing the value of the product RC. We can change R by changing the output tube or by using a transformer between it and the speaker, and we can change C by using different numbers of sections in the speaker or for special purposes by connecting groups of sections in series-parallel. The series-parallel connection is not very desirable for most installations as it complicates the biasing circuit. It may be mentioned that we can increase R by merely inserting an auxiliary resistance in series with the speaker. This is not very desirable as we thereby improve the frequency response only at the expense of efficiency.

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With the present type of 8 in. by 12 in. units a value of about $RC = 65$ (R being expressed in ohms and C in μf gives the flattest frequency response for a small speaker of four 8 in. by 12 in. sections, while $RC = 100$ gives the best result on a speaker of, say, six sections. The difference is due mainly to the fact that the high frequencies emerge in a beam and that the beam is sharper with the larger speaker.

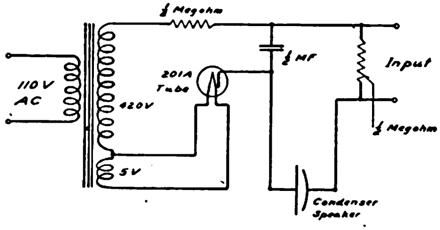

Fig. 5—Biasing Unit for Kyle Speaker.

The higher value of RC gives less total response in the high frequencies, but on account of the fact that they are more effectively concentrated on the listener in the usual listening position, the effect is practically the same.

If an exceedingly large speaker is built the beam effect becomes rather objectionable if the sections are all used in the same plane. A 24-section speaker was found to give good response over an angle

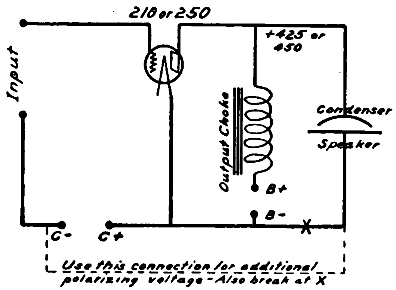

Fig. 6—Use of Plate Voltage for Biasing Kyle Speaker.

of about 30 deg. using a value of $RC = 180$, but outside of this angle the high frequencies were low in intensity.

A 48-unit speaker designed for talking picture reproduction is shown in Fig. 3a. This unit is inserted integral with the sound transparent picture screen and can be hoisted as a fly.

If the front of the speaker is set on a curved surface instead of flat, the beam effect can be utilized to cover just the horizontal angle desired, keeping the vertical divergence small. The sound can then be

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focussed to cover the auditors without projecting a large proportion toward the ceiling. When used in an auditorium there is some effect in reducing the reverberation as the total energy input into the room for a given loudness to the auditors is smaller than it would be if the sound were projected uniformly in all directions, and in addition the sound is projected toward a good absorbing surface, the audience.

A 96-section speaker was built on these principles to cover a horizontal angle of about 90 deg. It was found that the best frequency response was secured with $RC=60$.

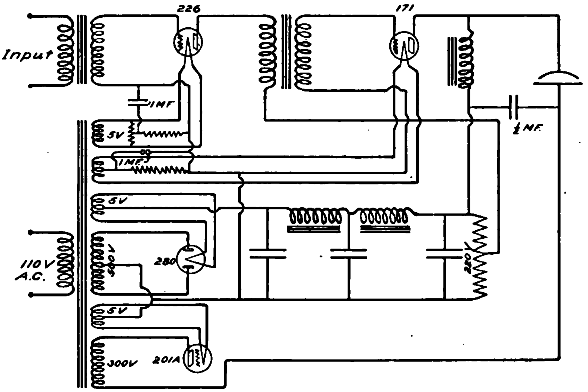

Fig. 7—Adaption of Amplifier and Power Back to Kyle Speaker.

In matching the speaker to an amplifier the characteristics of the amplifier, of course, have an important bearing. For example if the amplifier has a rising response characteristic toward the high frequencies it is possible to use a higher value of RC than if it were flat.

As shown above the force on the diaphragm at the desired frequencies is proportional to the product of the biasing potential and the alternating input voltage. This means that the energy output with constant input is proportional to the square of the biasing voltage. Practically this is only true within limits. If the biasing voltage is carried too high the diaphragm is drawn tightly against the back plate and placed under considerable tension. The result is a decrease in efficiency, rather than an increase, especially on the low frequencies. With the units constructed as at present a biasing voltage of 500-600 is as high as should be used.

Figs. 5 to 7 illustrate circuits applying the Kyle reproducer. Fig. 5 is the circuit of the biasing unit which is used with the individual speaker to be attached to any radio set. The 201A tube has proven a very satisfactory rectifier for this service as the current drain is practic-

ally nil. It will be noted that no filtering circuit is included. This is possible because no current is used in biasing the speaker. The charge on the speaker builds up until the voltage reaches that of the peak after which no current flows and no hum is perceptible.

Fig. 6 shows the simplest connection possible, no auxiliary apparatus whatsoever being used. If the connection to $-C$ is used the impedance between $+C$ and $-C$ should be small, otherwise a bypass condenser should be used from the speaker to $+B$ and a grid leak inserted between the speaker and $-C$.

Fig. 7 shows means for adapting the power pack of an amplifier to furnish biasing voltage in excess of that furnished in the plate voltage. These diagrams are not intended to show all the possibilities by any means but only to illustrate the requirements.

In cases where the speaker is to be built into the radio set the problem of installation is fairly simple. The speaker units may be made to cover practically the entire front area of the console, leaving narrow spaces for bringing through the set controls. Some very satisfactory models have been made up in which all controls were eliminated from the front of the console, the control knobs being placed at the end and the indicating dial appearing on top.

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DETECTION AT HIGH SIGNAL VOLTAGES
Part 1
Plate Rectification with the High-Vacuum Triode*

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I. Introduction

During the past five years an abundant literature has grown up dealing satisfactorily with the detection of *small signals* both from the theoretical and experimental viewpoints. A convenient theory can be formulated mathematically when the applied voltages and the higher tube parameters are small by means of the series method first employed by Carson in discussing the plate circuit. This has been done by Carson[1] for detection in the plate circuit, and by Lewellyn[2] and Ballantine[3] for rectification in the grid circuit.

The performance of the detector in the more complicated case in which the signal voltage and higher order tube parameters are high, however, does not seem to have been accorded much experimental attention, nor does the theory seem to have been satisfactorily worked out. It may be noted from the mathematical side that as the carrier voltage is increased the higher order terms in the Carson series formulation become increasingly important and the computations from it soon become laborious beyond the point of usefulness for ordinary purposes of investigation. Chaffee has devised an ingenious theory in terms of closed integrals over the usual d-c characteristics and certain differential parameters of the detector which offers some advantages in computation over the series method, but these are hardly sufficient to make it a practical tool of investigation.

In my own work in this field I have employed three methods of investigation:

(1) A descriptive theory which attains its greatest simplicity in the case of a purely resistive load in the plate circuit, when a graphical solution can be obtained;

* Dewey decimal classification: R134. Original paper received by the Institute, March 15, 1929. Presented at the R. F. L. Engineering Conference held at Boonton, N. J., January 9, 1929; part presented in a paper entitled "Recent Radio Developments" at the meeting of the Philadelphia Section, Institute of Radio Engineers, May 21, 1926. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] J. R. Carson, Proc. I. R. E., **7**, 187; April, 1919.
[2] F. B. Lewellyn, *Bell Sys. Tech. Jour.*, **5**, 433; July, 1926.
[3] Stuart Ballantine, Proc. I. R. E., **16**, 593; May, 1928.

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(2) A mathematical theory, formulated as an infinite series in powers, not of the carrier voltage E_0, but of the product of the carrier voltage and the degree of modulation m. This formulation is based upon experimentally determined *rectification diagrams* in the same way that the old E_0 formulation rests upon the ordinary d-c characteristics. These rectification diagrams are as easily obtained experimentally as the d-c characteristics and by taking this step experimentally, instead of mathematically as is virtually done when the power series in E_0 is employed, the labor of calculation is considerably lightened;

(3) An experimental study of the whole process, including the generation of harmonics, i.e., non linear distortion. This experimental program was begun in 1922 and although it is still far from complete the main facts have probably been discovered.

The object of the present series of papers, of which this is the first, is to outline the experimental results in certain typical cases of: (1) plate rectification, (2) grid rectification, (3) grid and plate rectification, (4) special arrangements for linear detection, (5) diode and simple rectifiers (e.g. crystals), and also to suggest a rational basis for engineering design and the prediction of performance from diagrams which can be readily obtained experimentally.

II. Classification of Signals

Standard Symmetrical Modulated Signal. Before embarking upon a discussion of detection we may as well state our point of view as to the signal to be detected. In Fig. 1 a group of modulated signals is represented in three different ways. At the top the actual variation of

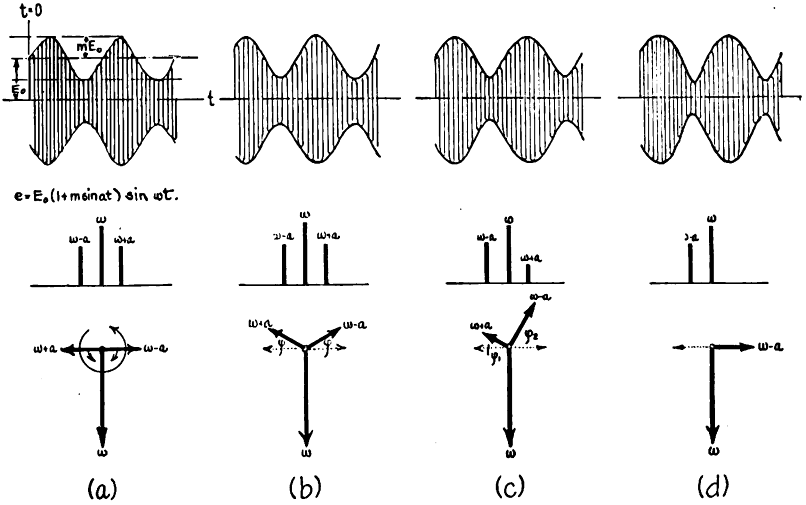

Fig. 1—Group of Modulated Signals. (a) standard symmetrical signal; (b) symmetrical phase shift in sidebands; (c) asymmetrical signal; (d) superior sideband suppressed.

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voltage is represented against time; the middle diagram represents the amplitudes of the component frequencies in the Fourier-series resolution of the signal; the lower diagram shows how these components combine vectorially to form the signal.

We shall adopt as standard the symmetrical modulated signal shown at (a), Fig. 1, which is of the type used extensively in radiotelephony and radio broadcasting. This signal comprises a carrier E_0 and two sidebands, symmetrical in amplitude and phase. Unless the contrary is stated it will be supposed that the modulation of the standard signal is of a single audio frequency, the carrier being of radio frequency. A signal of this type may be represented by:

$$e = E_0(1+m \sin at) \sin \omega t$$

$$= E_0\Big[\underbrace{\sin\omega t}_{\text{Carrier}} + \underbrace{\frac{m}{2} \cos(\omega - a)t}_{\text{Inferior sideband}} - \underbrace{\frac{m}{2} \cos(\omega + a)t}_{\text{Superior sideband}}\Big]$$

in which m is the modulation coefficient, which may vary from zero to unity, and a represents the audio and ω the radio angular velocities, respectively. In the vector diagram in Fig. 1a the carrier ω rotates anticlockwise at speed ω; at the same time the superior sideband $(\omega + a)$ rotates anticlockwise at rate a, and the inferior sideband $(\omega - a)$ rotates in the opposite direction at speed a, *both with respect to the carrier.*

A question may arise as to whether the results of investigation with such an ideal signal can be applied to other types of signal, especially signals which may have undergone some distortion in the processes of amplification and transmission, or which have not left the modulator in such standard form. Let us consider a few simple cases of distortion that are likely to arise in practice.

Symmetrical Sidebands Displaced in Phase. In passing through an amplifier employing simple resonant circuits the phases of the sidebands will be changed and their amplitudes diminished symmetrically as shown in Fig. 1b. It is assumed that the circuits are accurately tuned to the carrier frequency. The effect of this is two-fold: (1) a diminution of the effective degree of modulation m, and (2) a shift in phase of the audio-frequency envelope of the modulated signal. If m' is the altered degree of modulation and ϕ is the symmetrical phase-shift, then:

$$e = E_0[1 + m' \sin (at - \phi)] \sin \omega t. \qquad (2)$$

The signal thus remains of our standard type (1) and the investigation will apply to it with the indicated modifications.

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Sidebands Asymmetrical in Amplitude and Phase. In the more general case in which the r-f amplifier circuits are not precisely tuned to the carrier, the sidebands will be asymmetrical both in amplitude and phase, as shown in Fig. 1c. The mathematical expression for this signal is complicated and will not be written down since it will not be of further use; it is sufficient to say that this signal is not of type (1), that is, the modulation is not sinusoidal. The conclusions from the standard signal will not necessarily apply to a signal so distorted.

As a special case under this, consider that of equal sidebands with asymmetrical equal phase displacements. This might be brought about by a shift to the phase of the carrier by an amount ϕ. We then have:

$$e = E_0[1 + m^2 \sin^2 at + 2m \sin at \cos \phi]^{1/2} \sin(\omega t + \phi). \qquad (3)$$

This is not of form (1) when ϕ differs from 0 or π.

One Sideband Suppressed. This type of signal is frequently employed in practice (e.g., in transatlantic radiotelephony) and is expressed by:

$$\begin{aligned} e &= E_0\left[\sin \omega t + \frac{m}{2} \cos(\omega - a)t\right] \\ &= E_0\left[1 + \frac{m^2}{4} - m \sin at\right]^{1/2} \sin(\omega t + \psi). \end{aligned} \qquad (4)$$

The superior sideband is absent (Fig. 1d). This signal is not of the standard type (1).

It is interesting to note, in connection with this signal, that when it is detected by means of a curvature (square-law) detector there is no distortion due to beating between sidebands of opposite sign. However, in a practical signal each sideband contains several component frequencies so that there will still be some distortion produced by the beating of the components within the remaining sideband.

III. Ideal Linear Detectors and Small-Signal Detectors

Care must be exercised when using the term "ideal detector" to specify the type of signal for which it is ideal. In general a detector is ideal when the audio output is an exact replica of the original modulating wave *impressed upon the modulator.* Such a definition may be objected to on the ground that other processes, such as amplification, transmission, and modulation, take part in the process. This objection is only superficial, for even though the signal may be distorted from type 1, or any other standard type that might be adopted, the detector may be ideal to the distorted signal, that is, it may correct any distortion that has been introduced.

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So far as the standard signal (1) is concerned an ideal detector is a *linear detector*, that is, one in which the instantaneous relation between audio output and r-f input is *linear*. It has long been recognized that such a linear detector may be found in a device the current-voltage characteristics of which are straight lines meeting at an angle as shown in Fig. 2. It is essential that the break occurs at the origin ($E=0$), and it can be brought there by suitable batteries.

Many unsuccessful attempts have been made to discover a practical device having these characteristics. Failing this the art has been content with small-signal (square-law) detection with devices which operate on continuously curved $e-i$ characteristics, at the point of

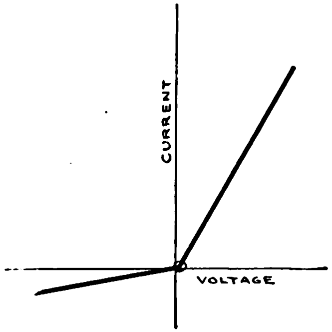

Fig. 2—E/I Characteristics of ideal linear detector for standard modulated signal.

greatest curvature. The inherent disadvantages of such curvature operation with a signal of the type $e=E_0[1+F(t)]$ sin at are well known.[3] The output of such a detector contains not only a term proportional to $F(t)$ as it should, but also a second-order $F^2(t)$ term which is superfluous and represents distortion. In order to limit this distortion the degree of modulation must be limited, that is $F(t)$ must be kept small compared with unity. This is uneconomical and wasteful of power in the carrier, and also limits the service area of a given broadcast transmitter for a fixed interference production by the carrier. I have been told that in the early days of radio broadcast transmission the transmitters were actually not capable of undistorted modulation of much more than 50 to 60 per cent. In English speech the "peak-factor" (the ratio of the maximum amplitude to the average amplitude) is stated by Sacia[4] to be about 5. This would mean that if in this case the maximum modulation were set at 50 per cent, the average modulation would be about 10 per cent. With such low modulation the non-

[4] Sacia, *Bell Sys. Tech. Jour.*, 4, 627; October, 1925.

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linear distortion with curvature detectors might not be noticeable, and this probably accounts for the complacent way in which the process of detection has been viewed by experts in this art.[5]

Feeling that the detector had been too much neglected, and looking forward to the time (now at hand!) when 100 per cent modulation would be generally employed in broadcast and telephone transmitters and the consequent distortion in square-law detectors would probably become important, I began, in 1922, an investigation to see what might be done toward securing at least approximately linear detection with circuit elements which were practically available. This program rested upon the fundamental idea that by taking a practical rectifier which was perhaps not quite of the perfect type shown in Fig. 2, but which had for example two slightly curved branches connected by a small section of greater curvature near the origin rather than by a definite break, or a curved portion and a straight portion (as in the case of a thermionic tube), and raising the applied signal voltage the action would approach linearity as the average curvature over each half-cycle decreased. In reducing this idea to practice I was fortunate in securing the collaboration of Dr. L. M. Hull, who made a survey of crystal rectifiers with the object of finding a combination of the requisite linearity from the high-voltage point of view. The broad principle of operating a detector at high voltages and an account of the successful work of Hull may be found in a U. S. Patent issued to Ballantine and Hull.[6]

Paralleling Hull's investigation of crystals, I undertook, simultaneously, a study of the action of thermionic devices with high signal voltages. While the relation between the thermionic current and voltage is known to be non-linear, the device is nevertheless recondite for the reason that at least *one* branch of the curve (zero current for retarding fields) is linear; hence the response may be expected to continuously approach linearity as the voltage is increased. This approach is further facilitated by reducing the curvature of the curved portion by the connection of linear impedances in the external circuit.

The soundness of this fundamental idea, and the improvement in the performance of a tube detector that results from increasing the signal voltage, is fully verified by the experimental results to be given later.

[5] As an example of this attitude we may quote from an article by Harvey Fletcher entitled "High Quality Transmission of Speech and Music" (Midwinter Convention, A. I. E. E., 1925) in which he says, referring to the usual small signal operation, that "in general there is no distortion in the detector."

[6] No. 1, 698, 668; January 8, 1929.

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IV. Descriptive Theory—Resistance Load

The action of the plate rectifying triode with high voltage signals of type (1) may be most simply exhibited when the external impedance is a pure resistance, for in this case a graphical construction may be employed. For simplicity the resistance load will be supposed to be by-passed for the carrier and neighboring frequencies, although a more nearly linear but less sensitive detection will be obtained if it is not by-passed. No inquiry will be made into the actual process of rectification, that is to say, no attempt will be made to derive the functional relation between the rectification current and the r-f grid voltage from d-c characteristics; this will be directly determined experimentally instead of the d-c curves. As the most fundamental relation we shall take that between the average plate current (as indicated by a d-c instrument), and the d-c plate voltage, for various r-f carrier voltages on the grid. This may be called the *rectification diagram for the tube,* and when, as in the case under consideration, the carrier is impressed

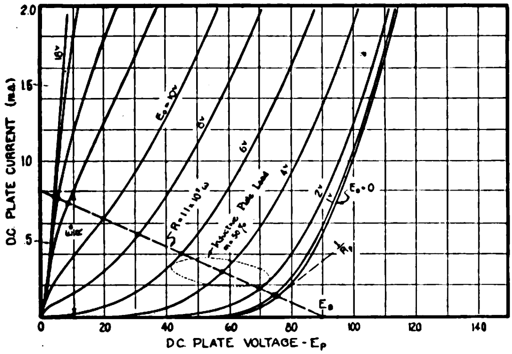

Fig. 3—Rectification diagram for triode. Relation between d-c plate current and d-c plate voltage with various r-f voltages on grid. 201A triode $E_c = -8$ volts.

upon the grid instead of being directly inserted in the plate circuit, we will call it the *transrectification diagram for the tube.* Such a diagram has been independently employed by Smith.[7] Fig. 3 is a typical experimental diagram for the 201A type of tube, $E_b = 90$ v, $E_c = -8$ v.

To determine the output we want the relation between the d-c voltage developed across the resistance load R in the plate circuit and the r-f voltage applied to the grid. In the case of the resistance load this may be determined graphically, as shown in Fig. 3. The voltage drop across R and the actual plate voltage are given by the inter-

[7] V. G. Smith, Proc. I. R. E., **15**, 525; June, 1927.

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sections of the straight line $I_p=(E_b-E_p)/R$ and the I_p-E_p curves. We can now construct a diagram of E_r vs. E_0. This will be called a *detection diagram;* if desired the data for this diagram may be directly obtained experimentally. In Fig. 4 the curve marked "$E_c=-8$ v" corresponds to the graphical solution of Fig. 3. The other curves correspond to other values of grid bias, E_c. The dashed curve marked "grid current" indicates the voltages at which grid electron current begins to flow.

We see at once from Fig. 4 what happens when our standard signal (1) is impressed upon the grid. This signal is an r-f voltage of variable amplitude, the variation comprising two parts, a constant part and a sinusoidally variable part. It is helpful to compare the process with that of amplification. In this analogy the Fig. 4 detection characteristic is analogous to the I_p-E_g characteristic of the amplifier, the carrier

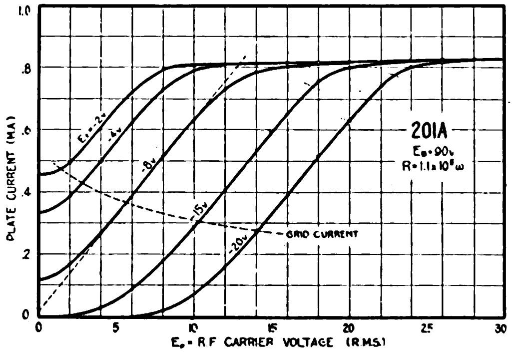

Fig. 4—Detection diagram for triode with 110,000-ohm resistor in plate circuit. Relation between plate current (d.c.) and r.f. voltage on grid.

voltage E_0 is analogous to the grid bias E_c of the amplifier and determines the "operating point," and the sinusoidal modulation $mE_0 \sin at$ is analogous to an alternating voltage of the same type applied to the amplifier grid. The curvature of the detection diagram will produce distortion in the same way that curvature of the amplifier characteristic produces it, and with a signal of type (1) the output will in general comprise a fundamental of modulation frequency and a group of harmonics.

With small signals the only part of the detection diagram of interest is that at the extreme left (E_0 small). The curvature of the characteristic in this region is compatible with the distortion calculated from the small-signal theory (Sect. III). We can obviously never hope to obtain demodulation free from distortion in this range of E_0.

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As the carrier voltage is increased the curvature decreases and finally vanishes at a point of inflection. Obviously this is the best operating point. Here the detection is actually linear and the harmonics and distortion reach a minimum. This bears out the soundness of the idea of high-voltage operation as outlined in Sect. III. Experimental curves will be given later which actually show that the harmonics are minimum and that the relation between carrier voltage and fundamental output is of the first order at this point.

As the voltage E_0 is increased beyond the point of inflection the curvature increases rapidly and the distortion becomes even greater than in the region of small signals. The output also falls off due to the "saturation" course of the curve.

V. Mathematical Theory for Small Modulation and Large Carrier Voltage

Starting with the usual d-c characteristics of the tube we can build up a theory of detection by the Carson series method in which the output is expressed as an infinite series in powers of E_0 and m. Even in the most favorable case of small m, however, this formulation becomes exceedingly tedious for large carrier voltages. It is proposed here to abandon the d-c characteristics entirely and start with the experimentally determined rectification characteristic for the tube (see last section). A new theory can then be built up in a series in powers, not of E_0, but of mE_0, and the various differential parameters of the *rectification characteristic.* What we are virtually doing here is pursuing the amplifier analogy. In the case of the standard signal mE_0 corresponds to the amplitude of a sinusoidal voltage impressed on the grid of an amplifier. The practical usefulness of such a formulation is confined to small values of mE_0, but this restriction does not seriously limit its instructive value, for we can still find out what happens at large E_0 by appropriately diminishing m. It is especially valuable as a supplement to the descriptive theory when the plate load is not a pure resistance and the graphical method is no longer available. In particular it furnishes several new concepts of engineering value. Among these is that of an *effective plate resistance for detection,* which is useful in designing the output apparatus for maximum transfer and fidelity.

Let e represent the instantaneous amplitude of the r-f voltage impressed on the grid, exclusive of the steady biasing voltage E_c; let i_p represent the rectified current in the plate circuit and let e_p represent the instantaneous plate voltage. Let it be supposed that the set of rectification characteristics $I_p=f(E, E_p)$ has been experimentally determined. This functional relationship may presumably be expressed in a double Taylor's series.

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$$I_p = P_1E + P_2E^2 + P_3E^2 + Q_1E_p + Q_2E_p^2 + \cdots + R_1E_pE + R_2E_p^2E + \cdots$$

where

$$P_1 = \partial I_p/\partial E; \qquad P_2 = \tfrac{1}{2}\partial^2 I_p/\partial E^2; \; + \cdots$$
$$Q_1 = \partial I_p/\partial E_p = g_p; \qquad Q_2 = \tfrac{1}{2}\partial^2 I_p/\partial E_p^2; \tag{6}$$
$$R_1 = \frac{\partial^2 I_p}{\partial E \partial E_p}; \quad \text{etc.}$$

The parameter $P_1 = \partial I_p/\partial E$ is of the dimensions of a conductance and is analogous to the mutual conductance of the amplifier tube. It represents the rate of change of the rectified plate current with respect to the amplitude of an alternating sinusoidal voltage applied to the grid. In view of the fundamental nature of this parameter it will be convenient to have a special name for it and until a more felicitous term appears I shall call it the *transrectification factor*, or shortly, the *transrectification*. The parameter $1/Q_1 = 1/\partial I_p/\partial E_p$ corresponds to the plate resistance R_p of the amplifier theory, and there is no need to change the term. It is important to note, however, that R_p is now a function of the carrier voltage as well as of the plate and biasing voltages. This fact might be kept in mind by some such term as the *detection plate resistance*.

Following Carson we wish to express i_p finally in the form:

$$i_p = a_1e + a_2e^2 + a_3e^3 + \cdots . \tag{7}$$

Now the alternating part of the plate voltage $e_p = -i_pZ$, where Z is the external impedance in the plate circuit. For simplicity we shall confine ourselves to the case where e is a sinusoid of single frequency, that is

$$e = \tfrac{1}{2}(Ee^{i\omega t} + \bar{E}e^{-i\omega t}).$$

The bar denotes the conjugate of the unbarred symbol. Let

$$i_p = i_1 + i_2 + i_3 + \cdots . \tag{8}$$
$$e_p = e_1 + e_2 + e_3 + \cdots \tag{9}$$

and substitute in (5). We have to deal here with a function of two unrelated variables and a double power series. The situation is the same as in Llewellyn's[2] extension of Carson's theory which removed the restriction of van der Bijl's relation (constant μ) between the variables E_g and E_p. Except for this the remaining work is virtually the same as that given by Carson[1] and need not be repeated. The results for the effects of the first two orders may be concisely stated as follows:

First Order Effect. Equivalent Circuit of the Detector. The first order output can be calculated by assuming a hypothetical voltage

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$=P_1e/Q_1$ operating in a circuit comprising an external impedance Z and the detection plate resistance ($R_p=1/Q_1$) in series. The current will be given by

$$I_1=\frac{\partial I_p}{\partial E}\frac{R_p}{R_p+Z}e. \tag{10}$$

This is the equivalent circuit of the plate rectifying detector, and is analogous to the equivalent circuit theorem for the amplifier which was originally stated by Carson; the transrectification factor $\partial I_p/\partial E$ in this case replaces the mutual conductance of the amplifier theorem. The calculation of the detection for small mE_0 is thus reduced to a simplicity comparable with that of the fundamental amplifier circuit. One of the chief practical contributions of this theory is that it defines an "effective plate resistance for detection," and enables us to see what happens when the external circuit is not a pure resistance and the detection diagram of Fig. 4 cannot be used to predict the output. With an inductive load, for example, and a sinusoidal modulation, the voltage-current relation during a cycle of modulation no longer describes a straight line in the Fig. 3 diagram, but an ellipse.

In the case of the standard signal (1), e in (10) is to be replaced by $mE_0 \sin at$ giving

$$I_1=mE_0\frac{R_p}{R_p+Z(a)}\left[\frac{\partial I_p}{\partial E}\right]_{E=E_0} \tag{11}$$

$Z(a)$ being the impedance for the modulation frequency $a/2\pi$. The value of $\partial I_p/\partial E$ is to be taken at the carrier voltage E_0. This derivative may be determined graphically from the data of Fig. 3 for the tube, or may be measured experimentally.

For small signals

$$I_p(\text{rect.})=\frac{1}{2}\frac{\partial g_m}{\partial e_g}\frac{E^2}{2}; \tag{12}$$

so that

$$\frac{\partial I_p}{\partial E}=\frac{E}{2}\partial g_m/\partial e_g \tag{13}$$

and

$$I_1=\frac{1}{2}\frac{\partial g_m}{\partial e_g}\frac{R_p}{R_p+Z}E^2, \tag{14}$$

which is the result given by the small-signal theory.

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Effective Plate Resistance for Detection. The quantity $R_p = 1/Q_1 = 1/\partial I_p/\partial E_p$, which has been referred to as the "detection plate resistance," can be evaluated graphically from the rectification $I_p - E_p$ diagram, Fig. 3. It is often preferable to measure it directly and a

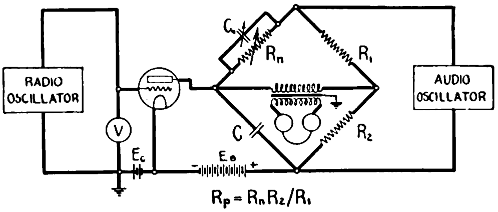

Fig. 5—Bridge arrangement for measuring effective plate resistance for detection.

convenient method for this is shown schematically in Fig. 5. This is an ordinary bridge arrangement already in use for measuring the amplifier R_p with the difference, however, that a r-f carrier voltage E_0 is connected to the grid during the measurement. C is a bypass condenser whose effect on the balance is compensated by C_n.

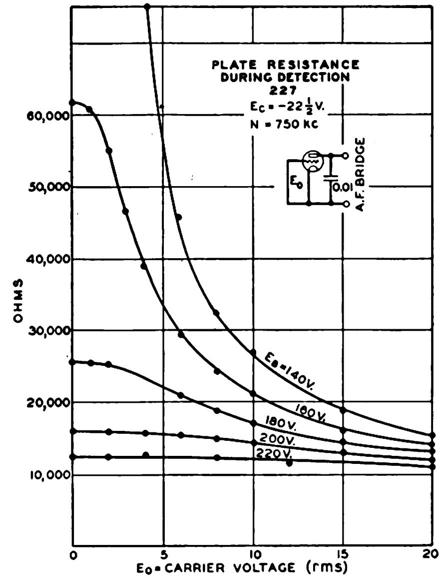

Fig. 6—Illustrating variation of effective plate resistance for detection with the variation of r-f voltage on grid. 227 triode; $= -22.5$ volts.

Typical results of such measurements are shown in Fig. 6. These data were taken with a 227-type triode with a grid bias of −22.5 volts. The different curves correspond to different plate battery voltages.

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The values of R_p for $E_0=0$ are the quiescent values which are significant in the amplifier theory. Note the dependence of R_p on the carrier voltage, especially for the lower battery voltages. These curves will be further discussed in Sect. IX.

Second-order Terms. Distortion. The second term in our series formulation (8) is of the second order in e, and can be regarded as the result of a hypothetical voltage

$$-(P_2e^2+R_1ee_1+Q_2e_1^2)/Q_1, \tag{15}$$

acting in a simple circuit comprising the external impedance and R_p in series. Here e_1 is the voltage between plate and cathode due to the first-order current (10). The voltage (15) will generally comprise several frequencies.

As an illustrative case consider our standard signal (1) and a purely resistive plate load, R. The second-order current is

$$i_2=\frac{m^2E_0^2}{4}\,\frac{R_p}{R+R_p}\left[\frac{\partial^2 I_p}{\partial E^2}-r\frac{\partial}{\partial E_p}\left(\frac{\partial I_p}{\partial E}\right)^2+r^2\left(\frac{\partial I_p}{\partial E^2}\right)^2\frac{\partial^2 I_p}{\partial E_p{}^2}\right](1-\cos 2at) \tag{16}$$

where $r=RR_p/(R+R_p)$. This contains a double-frequency term ($\cos 2at$) which represents distortion.

To make connections with the small-signal theory as expressed in terms of d-c characteristics, assume for simplicity, van der Bijl's relation (constant μ); then

$$i_p=\cdots\frac{1}{2}\left\{\frac{\partial^2 I_p}{\partial E_g{}^2}e_g{}^2+2\frac{\partial I_p}{\partial E_g\partial E_p}e_pe_g+\frac{\partial^2 I_p}{gE_p{}^2}e_p{}^2\right\} \tag{17}$$

$$I_p(\text{rect.})=\frac{1}{2}\,\frac{\partial g_m}{\partial e_g}\left[\frac{E^2}{2}+\frac{E_p{}^2}{\mu^2}\right]=f(E,E_p) \tag{18}$$

Substituting the values of the various derivatives of (18) in (16) we get:

$$i_2=\frac{m^2E_0^2}{8}\,\frac{\partial g_m}{\partial e_g}\,\frac{R_p}{R+R_p}\left\{1+\left(\frac{RR_p}{R+R_p}\right)\frac{E_0{}^2}{\mu^2}\right\}(1-\cos 2at). \tag{19}$$

The second term in the brackets is of the order of E_0^4 and will be disregarded for small E_0^2. Comparing (19) with I_1 as given by (10) we see that the distortion (I_2/I_1) approaches $m/4$ as E_0 approaches zero. This is the result given by the small-signal theory. Note that for small signals, to the order of quantities that have been retained, the external

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impedance is without effect upon the distortion. This is in contrast with the well known effect of an external impedance in an amplifier circuit in reducing the harmonics relative to the fundamental. With high-voltage signals, however, the external impedance does affect the distortion; this is already beginning to show up in the E_0^4 term in the brackets of (19).

VI. Definition of Distortion

With respect to the standard modulated signal (1) we shall have occasion to speak of two kinds of distortion: (1) *frequency distortion* as manifested by the departure of the output-modulation-frequency relation from uniformity, and (2) distortion arising from non-linearity whereby there appears in the output, in addition to the fundamental term of frequency, a, a series of harmonics of frequencies $2a, 3a, \cdots$ The latter distortion will be defined as the ratio of the r.m.s. value of the combined harmonics, as measured by an ordinary thermocouple meter, to the r.m.s. value of the fundamental. Denoting by E_1 the amplitude of the fundamental, and by E_n that of the nth harmonic, this definition may be expressed by:

$$\text{Distortion} = \left(\frac{E_2{}^2 + E_3{}^2 + \cdots E_n{}^2}{E_1{}^2} \right)^{1/2}$$

The convenience of this definition in experimental work resides in the fact that a thermocouple meter, responding according to the square law, indicates $(E_1 + E_2 \cdots)^{1/2}$ regardless of the relative phases of the components.

VII. Experimental Technique

The apparatus employed in the experimental study of detection is somewhat complicated, and to avoid interruption a detailed description of it will be postponed until the final paper of this series. For the present purposes a brief outline of the experimental method will suffice.

Standard Signal Generator. The first requisite for this work is a standard signal of type (1) of which the modulation can be varied up to 100 per cent, and the carrier voltage to about 100 volts. This signal is required to be of unusual purity, that is, the audio envelope should contain no harmonics, and the r-f carrier should also preferably be sinusoidal. None of the usual systems of modulation which were tried successfully met the requirements of range and purity, but after some investigation a satisfactory signal was secured from a new modulator which will be separately described. The modulation was performed

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at low voltages and the signal was brought to the desired level by means of a broadly tuned amplifier. Since the degree of modulation used was never less than 20 per cent, no trouble was experienced from the high shot-noise/signal ratio which this procedure might have been expected to produce.

Measurement of *m*. The degree of modulation *m* was measured at the grid terminals of the detector by means of a special meter, based upon the method of Posthumous and van der Pol. This meter will be described elsewhere. The method was found accurate, convenient, and decidedly superior to the more common methods. The modulation meter contained a buffer amplifier which was perfectly monodic, and did not affect the circuit across which it was connected.

A sensitive check on the purity of the signal and the accuracy of the measurement of *m* is afforded by the measurement of the percentage of distortion (ratio of second-harmonic to fundamental) in the

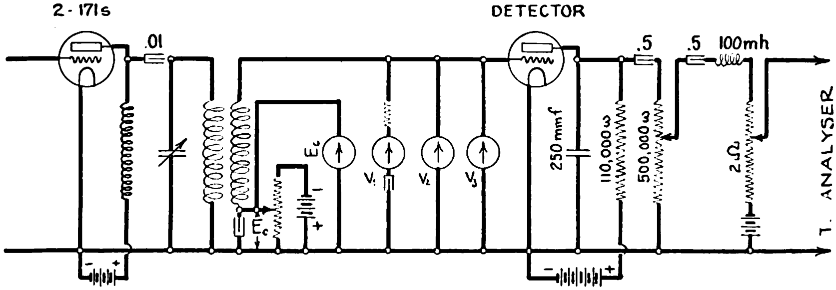

Fig. 7—Connections of triode for plate rectification as employed for experimental work. Resistance output.

detector at low signal-voltages. This ratio should approach $m/4$, and will be seen to do so in Fig. 8. This is evidence of the proper working of the apparatus, including the analyzer.

Connections for Plate Rectification. The actual circuit connections of the detector are shown in Fig. 7. The external impedance is shown as a pure resistance. The method of supplying the signal voltage to the detector grid is also shown. This is of importance when the grid takes current, since the load on the supply circuit occasioned thereby is non-linear. The effect of a non-linear load is to produce a distortion of the signal by lowering the peaks relative to the troughs in a non-sinusoidal fashion. The course of the curves for carrier voltages in the region of grid current depends, therefore, somewhat on the supply circuit. To reduce this effect two 171 tubes operating at 200 volts on the plate are used in parallel and the output transformer is designed to minimize the impedance change due to the grid current in the de-

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tector tube. No attempt has been made to eliminate it completely. This was done at first by using higher power tubes and more inefficient transformer design, but was later considered to be unnecessary in view of the fact that there is no standard method of supplying the detector tube and the practical value of the results would be no greater. In a practical test and in actual design the whole amplifier should be measured with the detector, or if the amplifier is known to be linear over the range of voltages to be used, the stage preceding the detector should at least be included.

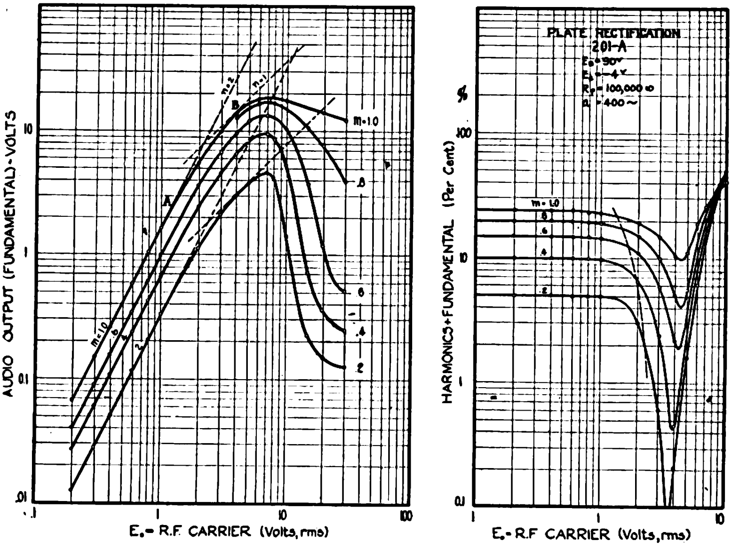

Fig. 8—Resistance Output. (left) Relation between fundamental output and carrier voltage in standard signal; (right) percentage of harmonics (distortion) versus carrier voltage. 201A triode, m = degree of modulation.

Analysis of the Detector Output. The audio voltage across the output terminals of the detector was measured and analyzed with regard to the amplitudes of the fundamental and harmonics. The method of analysis was as follows: The fundamental and all harmonics, that is to say the quantity $(E_1^2+E_2^2+E_3^2+\cdots)^{1/2}$, was first measured. The fundamental E_1 was then eliminated in an early stage of the analyzer by means of a Wheatstone bridge having one tuned arm, the remaining arms being resistive. A second measurement then gave the quantity $(E_2^2+E_3^2+\cdots)^{1/2}$. The distortion as defined in Sect. VI can be directly computed from these data. If the harmonics are small $E_1^2 \gg \Sigma E_n^2$ and the first measurement can be taken as giving the amplitude of the fundamental with negligible error; other-

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wise a suitable correction is to be applied. The fundamental may also be measured by tuning a stage of the amplifier associated with the analyzer to this frequency. A further "microanalysis" of the amplitudes of the individual harmonics can be made, with the fundamental eliminated, by means of a selective amplifier and output system. In this work it was found sufficient to carry this only as far as the fourth harmonic, as this summation accounted for the total harmonic effect within a small error.

The use of the Wheatstone bridge for the elimination of the fundamental is exceedingly convenient and avoids errors which would arise from the generation of harmonics in the post-detection amplifier and selective analyzer if the fundamental were permitted to enter it. I have employed this scheme for several years in this and other investigations but find that it has been fully described by Belfils.[8] A full description of the analyzer apparatus and details of its manipulation will be given separately.

VIII. Typical Experimental Results—Resistance Load

In presenting the experimental picture we may profitably confine the discussion to a typical case; in order to make comparisons with the descriptive theory of Sect. IV and the experimental rectification data of Figs. 3 and 4, we shall take that of a resistance load of 100,000 ohms in the plate circuit of a 201A type triode with $E_b = 90$ v, E_c at first equal to -4 v, later variable.

The range of carrier voltage extended from 0.1 to 50 volts (r.m.s.). Logarithmic coordinates were used on account of the wide range of magnitudes. The frequency of modulation was 400 cycles; separate tests at 100 and 2000 cycles showed that with a resistance load no difference in the results was to be expected at other frequencies. The carrier frequency was 600 kc (500 m).

Fundamental Output. The relation between the carrier E_0 and the fundamental (400-cycle) output voltage across the R-load for various degrees of modulation (20, 40, 60, 80, 100 per cent) is shown in the left-hand curve of Fig. 8. For carrier voltages up to the point A the output varies as E_0^2 in agreement into the theory for small signals. Beyond this point the small-signal theory begins to fail and the response approaches linearity ($n = 1$), which it attains at point B. This is the value of E_0 at which the distortion is a minimum and corresponds to the point of inflection on the detection diagram, Fig. 4, $E_c = -4$ v.

[8] G. Belfils, *Rev. Gen. d'Elec.*, 19, 523; April 3, 1926. G. Chiodi, *Electrotecnica*, 15, 166, 1928. The Belfils paper has evidently escaped the attention of I. Wolff (*Jour.* Opt. Soc. Amer.)

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Beyond B the output increases slightly and suddenly falls off; this will be referred to as "overloading." The overloading may be accounted for by the "saturation" character of the curve in Fig. 4. It occurs more suddenly the lower the modulation, being least marked for $m=100$ per cent.

Harmonics. Distortion. The variation of the combined harmonics, that is of the quantity $(E_2^2+E_3^2+E_4^2+\cdots)^{1/2}$, over the same range of E_0 is shown at the right of Fig. 8. The ordinates represent distortion as defined in Sect. VI. For low signal voltages the distortion approaches $m/4$ as predicted by the small-signal theory, and as noted previously, this furnishes a check on the performance of the apparatus. The distortion remains constant over the range of "small-signals", decreases as the carrier voltage is further increased, and finally reaches a minimum at a voltage corresponding to point B in the "fundamental" diagram. This has been predicted by the descriptive theory. Micro-analysis of the harmonics shows that up to and a little beyond the point B (20 per cent modulation) the second harmonic predominates, vanishing at B, and reversing sign in going through this point. The residual distortion at the minimum is largely composed of third harmonic. This harmonic increases rapidly with E_0 and m.

The dotted curve represents the points at which electron current begins to flow in the grid circuit of the detector tube.

With regard to the practical interpretation of these curves of distortion it has been my experience that the ear cannot detect with certainty a distortion of less than 5 per cent, so that the upper part of this diagram is probably the only part of significance.

The rather sudden rise in distortion which accompanies overloading will be noticed, the values attained being even higher than those for small-signal operation.

The experimental results of Fig. 8 again testify to the soundness of the idea of operating the detector at high signal voltages, thereby taking advantage of linearity.

Effect of Grid Bias. The qualitative effect of changing the grid bias can be gleaned from the detection diagram, Fig. 4. Under the conditions of that diagram the best bias, for modulations ranging up to 100 per cent, appears to be about -8 volts. Smaller bias voltages give less output because of the limited range of E_r. Higher biases result in a "cut-off" on the $E_r=0$ axis which introduces distortion at the higher modulations. With $E_c=-20$ v, for example, and E_0 adjusted to the optimum value (point B) this cut-off effect would appear at about $m=60$ per cent. Notice, however, that with a *limited m* the bias may be increased above -8 v with correspondingly better output; the smaller

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m is, the higher the bias may safely go before introducing distortion. The upper bend of the curve must also be taken into consideration; as a matter of fact it is usually more important than the lower, or cut-off, bend because the saturation is more abrupt. The detection diagram (Fig. 4) is very instructive on all these points, and many other practical conclusions may be drawn from it.

The corresponding experimental picture is presented in Figs. 9, 10, 11. The variation of the fundamental output with carrier, for 20 per cent modulation, is shown in Fig. 9 for several grid bias voltages (−2, −8, −15, −20 volts). These curves verify the qualitative deduc-

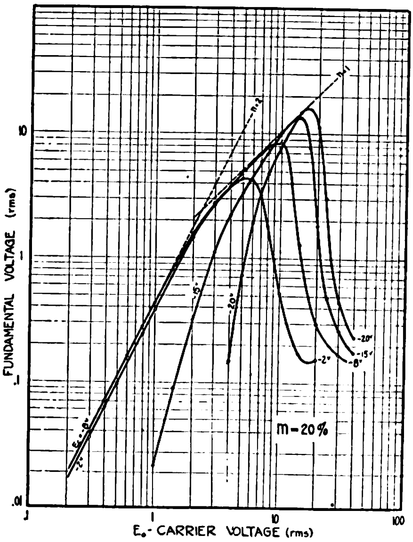

Fig 9—Resistance Output. Effect of grid bias. Relation between fundamental output and carrier Voltage. 201A triode; $E_b = 90$ v, $R = 110{,}000$ ohms, 20 per cent modulation.

tions from the descriptive theory. The maximum output for $E_c = -8$ v, for example, is about twice that for $E_c = -2$ volts. The small-signal behavior is normal for biases up to about −8 volts. The effect of the cut-off, that is obtained with biases of −15 and −20 volts, is to cause a variation of output more nearly as E_0^4 than as E_0^2. For this degree of modulation (20 per cent) an E_c greater than −8 v results in an ultimately greater output and the operation at the proper value of E_0 may be quite satisfactory and normal, even though unsatisfactory at small E_0.

The variation of distortion for the same changes of grid bias is shown in Fig. 10 for 20 per cent modulation, and in Fig. 11 for 100

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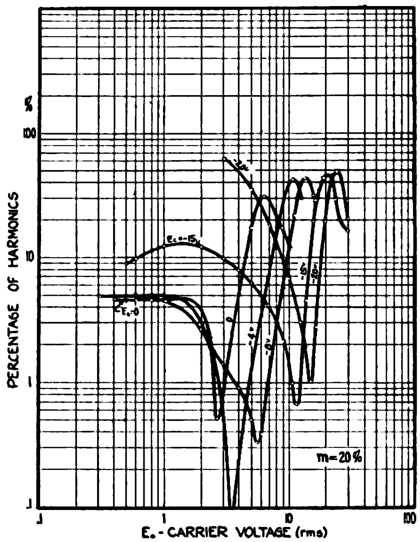

Fig. 10—Resistance output. Effect of grid bias. Relation between percentage of harmonics (distortion) and carrier voltage. Same conditions as in Fig. 9. Twenty per cent modulation.

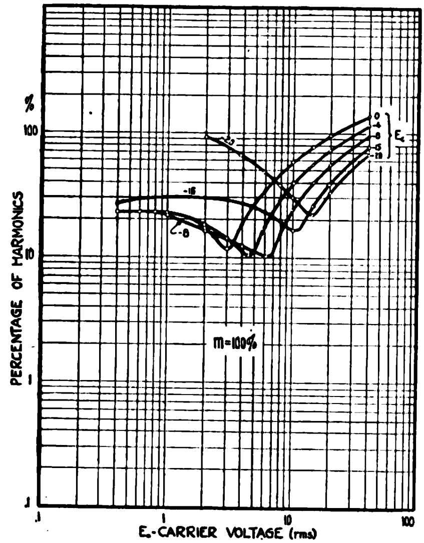

Fig. 11—Resistance output. Effect of grid bias. Same conditions as in Fig. 10 but with 100 per cent modulation.

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per cent modulation. With reference to Fig. 10 it will be seen that the lowest average distortion for $m=0.2$ is obtained with a bias of -8 v; this result checks the inference from Fig. 4. Note the abnormally large distortion for biases more negative than -8 v, i.e., in the cut-off range. The left-hand portions of these curves for $E_c = -15$ and -20 volts could not be followed further because the current became too small. The tendency toward the small-signal limit, $m/4$, shown by the -15 v curve, is probably only apparent.

The curves for 100 per cent modulation shown in Fig. 11 are generally similar to those for 20 per cent modulation. The value of -8 v as the best bias is further confirmed. By operating at the proper signal level the distortion is reduced from 25 per cent to 10 per cent. This improvement is readily perceived by the ear.

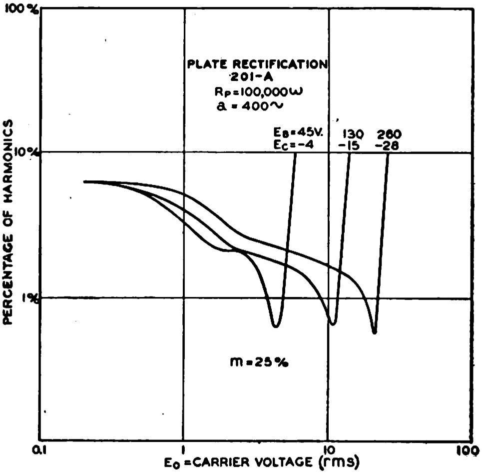

Fig. 12—Resistance output. Distortion versus carrier. Effect of changing plate and grid (bias) voltages simultaneously so as to preserve constant d-c plate current.

Effect of Plate Voltage. The effect of increasing the plate battery voltage is not particularly interesting, and if at the same time the grid bias is changed so as to preserve constant plate current, the curves just given are simply moved laterally toward higher E_0. This is illustrated by Fig. 12, which shows the distortion as measured with three combinations of plate and bias voltages selected on the basis of constant plate current. The harmonic curves in Fig. 12 do not agree exactly with those of Fig. 11 as the two sets of data were taken three years apart with entirely different apparatus, different tubes, and under different supply conditions. They illustrate, nevertheless, the

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shift of the phenomena toward higher E_0 which is characteristic of increasing E_b.

Relation between Fundamental Output and *m*. This relation is ultimately significant as an index of the fidelity of detection. The fundamental output should, of course, vary linearly with the degree of modulation, for a given carrier voltage. It should be noted, however, that this is not in itself a guarantee of the absence of distortion, for harmonics may still be present in the output. For example, with small signals the fundamental output varies linearly with m, but there is also present a double-frequency current which varies as m^2. With regard to the standard signal we may therefore make a further distinction between the kinds of distortion in detection due to non-linearity. We have: (1) a non-linearity in the relation between the fundamental and m, and (2) harmonics which are not present in the original signal. In

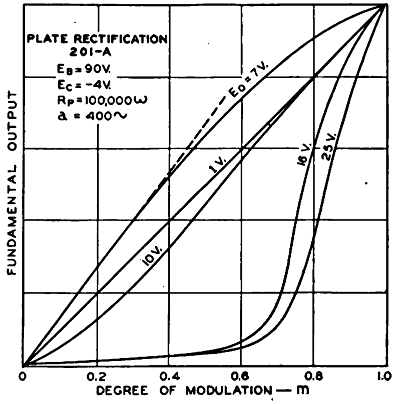

Fig. 13—Resistance output. Relation between fundamental output and degree of modulation for various carrier voltages.

the example cited above, of small-signal voltage and square-law detection, only the second kind of distortion is present.

The experimental relations between the fundamental output and the degree of modulation, obtained under the experimental conditions of the previous curves, are shown in Fig. 13. The grid bias is -4 v, and the several curves correspond to different carrier voltages. All curves have been reduced to equal output at $m=100$ per cent. The curve for $E_0=1$ v may be taken as representative of small-signal operation (see Fig. 8), and the output is proportional to m. While no measurements were made with a carrier exactly equal to the optimum value (point B in Fig. 8) it may be inferred from the curves that the relation will be nearly, if not exactly, linear. Note the considerable departures from linearity when the detector is overloaded ($E_0=16$, 25 volts).

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IX. Transformer Output Load

We have discussed the simple case of a resistive output impedance from both the descriptive and experimental viewpoints, have observed a satisfactory qualitative agreement between them, and have obtained a general idea of the way the detector operates at high signal levels. We may now turn to the consideration of other types of output impedance, for which the graphical method is not available. A case of practical interest is that of a transformer.

As previously remarked, the instantaneous relation between current and voltage now describes an ellipse on the rectification diagram in Fig. 3, and the detection diagram, Fig. 4, is multiple-valued and no longer significant. We may therefore turn to the mE_0 theory and particularly to the theorem expressed by equation (10) in order to obtain a starting point for design. According to this theorem the

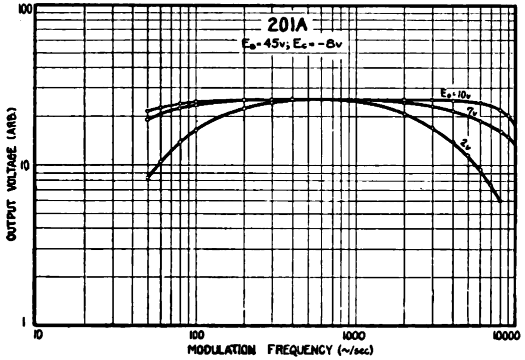

Fig. 14—Transformer Output. Effect of carrier voltage on fidelity; 201A triode; RFL 5B transformer.

problem of design for the detector is identical with that for an amplifier, provided the detection plate resistance, as defined in Sect. VII, is employed in place of the usual quiescent R_p. This is the gist of the whole matter and since amplifier design is well-known, no further discussion seems necessary.

The experimental relations between the fundamental output, distortion, and carrier voltage in the case of a transformer, at a definite modulation frequency, are very similar to those which have been shown in Figs. 8, 9, 10, 11, for a resistance. In view of this it does not seem justifiable to waste space reproducing the experimental curves, since they show nothing new. There is, however, one additional factor that does not appear in the resistance case, but which deserves discussion; this is the question of fidelity.

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Fidelity. The term *fidelity* is employed here in its usual sense as designating the relation between the fundamental output and the modulation (audio) frequency. In an amplifier stage the fidelity is determined by the transformer impedance and R_p; in this case, R_p is a function of the carrier voltage, so the fidelity will in general depend upon the signal level. The change of fidelity with E_0 can be predicted from an experimental $R_p - E_0$ diagram such as Fig. 6. This is a matter of considerable practical importance. If the same fidelity is desired at low and high signal levels, the plate and bias voltages must be chosen so that R_p does not vary much with E_0 (compare curve for 220 v in Fig. 6). A case in which these voltages are so chosen, that R_p varies considerably with E_0, is illustrated by the experimental fidelity curves in Fig. 14. These were taken with a 201A-type triode, with $E_b = 45$ v and $E_c = -8$ v.

X. Practical Applications

The most promising practical application of detectors operating at signal voltages, high enough to give linear response, as described in this paper, is probably to receivers for broadcast (entertainment) and telephone reception with signals of the standard type (1). Plate and grid rectifying detectors of this type have been incorporated in broadcast receivers designed by the Radio Frequency Laboratories for its manufacturing licensees.

The idea of applying signal voltages of the order of 1 to 100 volts to a detector may have sounded fantastic and uneconomical when first proposed by us in 1923,[6] but this could hardly be urged today. Shielded tetrodes have lately become available in commercial quantities, and furnish the required amplification conveniently and at low cost. As a matter of fact in broadcast receivers for the range of 545 to 1500 kc a certain minimum number of tuned circuits are needed to provide the selectivity demanded by present conditions, and if these are cascaded between tetrodes yielding an amplification of the order of 100 per stage, the output voltages will be entirely adequate for this purpose. If desired, and the voltages are available, the detector may also replace the output tube and operate the electrophone load directly. This may properly be termed "power detection" and has been employed (*vide* also Fig. 5, Ballantine-Hull patent cited above). A less extreme step consists in eliminating but one audio stage, retaining the power tube and operating it by the output of the detector.

There is no special difficulty in maintaining the signal voltage at the optimum point B (Fig. 8) by a manual control; nevertheless it is desirable in receivers designed for commercial use to make the adjustment for linearity as easy and as obvious as possible. Two methods for

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accomplishing this have been employed. In the first the carrier is maintained at its optimum value over a wide range (10,000 to 1) of field strength variation by means of the automatic volume control which I have previously described.[9] In the second method manual control is employed and the adjustment is facilitated by extending the range of E_0 over which the detector is linear by means of special devices which will be described in the fourth paper of this series. The practical feasibility of both methods has been demonstrated in R. F. L. commercial broadcast receivers.

In conclusion I wish to acknowledge my indebtedness to Dr. K. C. Black, Messrs. H. A. Snow, P. O. Farnham, and Raymond Asserson for experimental assistance at various times.

[9] Meeting of the Philadelphia Section, Institute of Radio Engineers, May 21, 1926.

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TRANSMITTING ANTENNAS FOR BROADCASTING*

By
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FOR many more years broadcasting will be of increasing importance for the general public. We radio engineers must therefore recognize what the future problems of the broadcasting technique will be, what has to be improved or developed. The main thing will be that everyone in the world will be able to receive broadcast performances without being bothered by technical deficiencies.

I do not intend to discuss these problems as far as receivers are concerned; I shall only refer to the future development of transmitters and transmitting antennas. The ways and means for the development of broadcasting transmitters and the possibilities of improvement are already more or less known and the technical development will certainly continue the way it has thus far pursued. Future improvements in this field will concern an enlargment of the frequency range on either side—in the future we shall probably have frequencies from 20 to 20,000 kc; also the modulation will have to be enlarged, and ratios of amplitudes of 1:1000 will probably be broadcast by the transmitters. Therefore we shall have to use transmitters of higher power. The increased transmitting power will result in increasing the range of interference. Therefore it may become necessary to couple many transmitters in groups and broadcast on the same wavelength. The broadcasting system will be such that all transmitters working on the same wavelength will have to transmit the same program. This will probably result in control of these transmitters by means of talking films running synchronously. Later on still higher demands must be satisfied with regard to the reproduction of music; that is, this will bring the broadcasting transmission to the following point: control of the transmitter without transmission cable between studio and transmitter, and use of sound records on films operated in the high-power transmitting station. This pertains more to broadcasting conditions in Germany.

In this way the radio engineer may foresee the future possibilities of development in the design of transmitters. The principles of this development are generally clear, but this is not the case with regard to the transmitting aerial.

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Which is the best broadcast aerial? Fundamental conditions for such an aerial are: greatest economy; largest service area of the transmitter, that is, no fading within a very large area around the transmitter; smallest interference area. By simply increasing the intensity of the transmitting energy we would not increase the service range but only the range of interference.

I wish to report to you how we have pursued these problems in Europe, particularly in Germany. Our intention was to modify the ratio between surface waves and space waves in favor of the surface waves. The radiation emitted from the aerial upwards at a certain angle must be reduced as far as possible. The aerials which are commonly used in broadcasting oscillate in a quarter wavelength. They might be considered as one half grounded dipole (half-dipole). Such aerials usually show fading at wavelengths between 400–500 m in a distance of 100–120 km due to the influence of the reflected space waves. In order to improve the ratio of the surface waves to the space waves, we use for transmission instead of the half-dipole a complete dipole suspended as high as possible. Thus instead of a quarter wavelength, the length of the aerial is now a half wavelength.

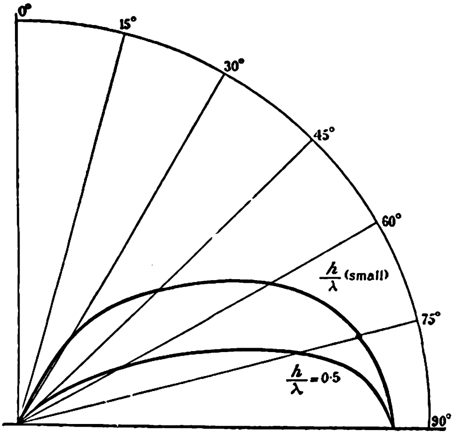

Fig. 1—Vertical Polar Diagram of Radiation for ½λ and ¼λ (or less) aerials. Drawn for the same maximum radiation intensity in the horizontal plane.

While the usual aerials for broadcasting have a current loop at the grounded point of the aerial, there is now a current node at said point, and hence a loop of potential. Such an aerial has an increased radiation horizontally parallel to the surface of the earth. Fig. 1 is taken from Eckersley's[1] recently published paper demonstrating the difference between these two aerials. In order to avoid possibility that the hori-

[1] P. P. a. T. L. Eckersley a H. L. Kirke, *Jour.* I.E.E., April, 1928.

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zontally emitted radiation from such an aerial be disturbed, it is necessary that the high supporting masts be insulated at the base. When iron masts are used care has to be taken that their natural wavelength does not coincide with the wavelength of the transmitter. Since the natural wavelength of the insulated metal mast is approximately equal to twice the height, one is obliged to accept the following compromise regarding the height of the mast: the height of the mast must be smaller than half the emitted wavelength and the antenna must be designed so that the center of capacity of the upper half of the dipole is still situated (approximately) at the same height it would be in the case of an aerial wire stretched vertically, and the length

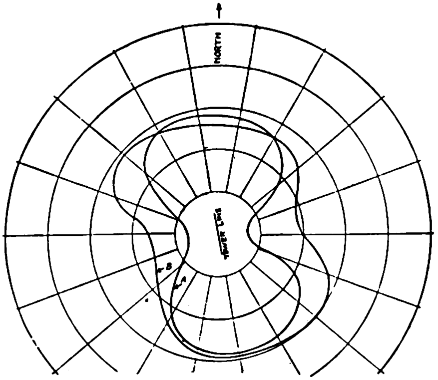

Fig. 2—Field Patterns of Vertical Antenna in Span B–F.
Pattern A—with towers resonant
Pattern B—with towers detuned

of the wire has to be $\lambda/2$. If the natural wavelength of the masts is of the order of the transmitted wavelength, the field distribution loses its symmetry. Fig. 2 shows such a distortion of the field with a $\lambda/4$ aerial from tests carried out by H. M. O'Neill[2] of the General Electric Company, Schenectady. In this case the distance between the masts and the aerial is larger than $\lambda/4$. The masts are 100 m high and are grounded at the base. The wavelength was 380 m. If the tuning of the masts is within the range of resonance, the field intensity in the direction of the masts is essentially higher than in the plane normal to said direction.

[2] H. M. O'Neill, Proc. I. R. E. **16**, 880; July, 1928. According to R. Beckmann the influence of the mast may be calculated by the following formula:

$$E = K \cdot \frac{J_a}{r} \sqrt{\left[1 + 2\frac{J_m}{J_a} \cos\left(\frac{\pi}{\lambda} d \cos \varphi\right)\right]^2 - 2\frac{J_m}{J_a} \cos\left(\frac{\pi}{\lambda} d \cos \varphi\right) \cdot \left(2 \sin \frac{\psi}{2}\right)^2}$$

In this formula J_a is the current in the aerial, J_m the current in the mast, ψ the azimuth angle, ϕ the phase of the current in the mast is a function of its natural vibration and the distance d/λ.

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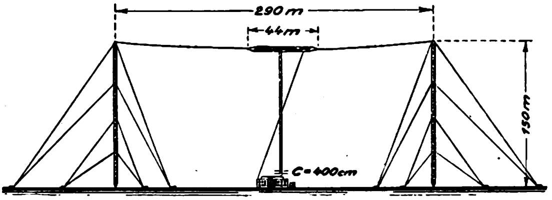
Experiments carried out by Telefunken in order to improve broadcasting aerials by using total dipoles were started early in 1926. Later on they were continued in cooperation with the German Telegraph Technical general-postoffice (Telegraphen-Techn.). Before 1926 it was not possible to use such aerials with a potential loop at the grounding point due to the fact that broadcasting transmitters with independent drive had not yet come into use. At that time it was recognized that although an ammeter in the earth connection indicated scarcely any current, aerials could nevertheless be energized if the transmitter was separately controlled by an auxiliary generator. From the intermediate circuit current and the plate current of the last amplifier stage the amount of energy transferred to the aerial could be estimated.



$\bar{\lambda} = 545$ m

$\lambda_0 = 930$ m

Fig. 3—Broadcasting Transmitter—Budapest.

This principle of using λ/2 aerials instead of λ/4 aerials formerly developed by Telefunken has proved to be correct and has been verified by tests recently made by Mr. Eckersley, the technical manager of the British Broadcasting Co. In order to avoid interference from the radiation effect of the aerial by the masts, these tests have been carried out with aerials supported by balloons. It was found that such an aerial of λ/2 height radiated an increased field intensity of 1:1.26 compared with an aerial of λ/4 height. But the most important fact, he found, was that with the λ/2 aerial, compared with the λ/4 aerial, fading could be reduced and that due to this reduction of fading the service area of the antenna was enlarged.[3]

I wish to explain to you the results that may be obtained in practice with such aerials, and for this purpose I would refer to the broadcast transmitter at Budapest which has been designed according to these

[3] For the German broadcasting transmitters having self-supporting masts of 100 m height the Telegraph-technical-office (Mr. W. Schäffer) since 1927 has also introduced the principle that the transmitted wave shall be 0.6 times the natural wavelength of the aerial.

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principles and has been operating now for about one year. This transmitter is especially known all over Europe for its wide range of transmission. It was built by the Telefunken Company under the supervision of the Hungarian Post and Telegraph Administration. The antenna (Fig. 3) is supported by two 150-m masts 290 m apart. The vertical aerial has a flat top extending horizontally about 22 m in both directions. The service wavelength is 545 m, the natural wavelength of the aerial being 930 m. The antenna is shortened at its grounding point by a capacity of 400 cm. By means of this capacity

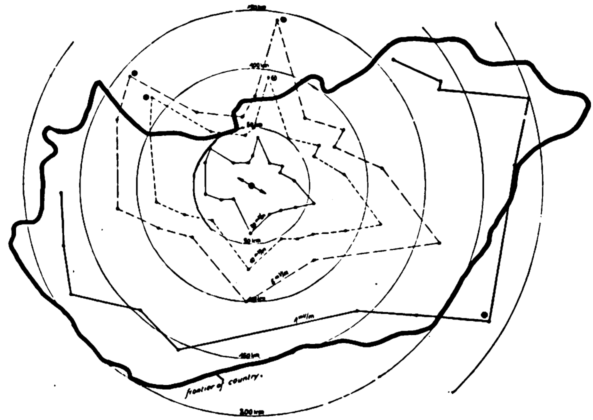

Fig. 4—Field Intensities—Budapest. 15 kw.

the aerial is at the same time coupled to the transmitter. The current loop lies approximately at half the height of the mast and the potential loop at the grounding point. Accordingly only few grounding wires are used. The earth resistance is not of great importance.

Fig. 4 shows the field intensities around the aerial with a transmitter output of 15 kw when not being modulated; these intensities have been measured by the officials of the Hungarian Post and Telegraph Administration.[4] The field intensities at different distances and in the two preferred directions were as follows:

at	50 km	about	30	mv	per m.
"	100 "	"	11	"	"
"	150 "	"	5	"	"

The distortion of the field intensity curve in the direction of the plane of the masts (indicated by the arrow) is caused by the influence of the masts. The insulator which serves to separate the mast from the rope supporting the aerial has by mistake been inserted in the

[4] S. Baczynski, *Telefunkenzeitung,* June, 1929.

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middle of this supporting rope so that by a rope of 61 m length the natural vibration of the mast was increased to about 450 m and approached that of the transmitted wave, thus causing a distortion of the field intensity in the direction of the plane of the masts. For the transmitter at Budapest, however, this distortion effect was very desirable since the Hungarian country is a narrow but long area, and because it had been required that this one transmitter at Budapest should provide, if possible, a field intensity which could be efficiently picked up at any place in the country.[5]

The following table shows the field intensities at various distances, i.e., 50, 100, and 150 km, measured around Budapest, Motala, the strongest broadcasting transmitter in Sweden, reduced to 15 kw,

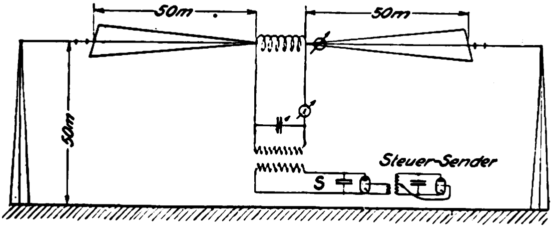

Fig. 5—Horizontal Antenna for Broadcasting.

and around an English high-power transmitter, according to P. P. Eckersley's[6] statement, which is also reduced to 15 kw.

TABLE I

	50 km	100 km	150 km
BUDAPEST 15 kw			
Favorable direction	30 mv/m	11 mv/m	5 mv/m
Average	19 "	5 "	1.4 "
MOTALA 15 kw			
Maximum	21 "	4.95 "	2.1 "
Average	12 "	3.2 "	1.2 "
ENGLISH STATION			
Average	13 "	4.22 "	1.5 "

But what has made the new antenna at Budapest particularly valuable and useful is the remarkable improvement with regard to fading. The observations made by the Hungarian Post and Telegraph Administration have shown that slight fading begins only at distances beyond 150 km, and in the direction of the plane of the masts fading will occur at greater distances. For normal aerials the limit for fading with this wavelength is from 100 to 120 km.

Another aerial similar to that at Budapest has just been completed at Oslo (Norway) by the Telefunken Company under the super-

[5] The disturbance of the field strength in Fig. 4 can be described by the formula in footnote 3, substituting in this formula the ratio of current in the masts to that in the antenna $=\frac{1}{6}$.

[6] P. P. Eckersley, *Jour.* I.E.E., 65, 600; 1927.

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vision of the Norwegian Post and Telegraph Administration. In this case an aerial 150 m high has been provided for working a wavelength of 496.7 m.

Though the problem of broadcasting aerials seems to have been considerably advanced, yet another question must be cleared: Is a horizontal aerial which is fed at its center by a feeder line better than a vertical aerial? During the tests carried out in 1926 (Fig. 5) in cooperation with the German General Post Office it appeared that the horizontal aerials were superior to the vertical ones within the broadcasting wave range up to 300 m if they were suspended at a height of about $\lambda/4$ above the ground, and this applies to the direction of the plane of the aerial as well as to the direction at right angles to it.

In the experiments self-supporting grounded masts were used. For waves beyond 300 m and under the conditions prevailing at that time (100-m grounded masts), the vertical aerial seemed to be superior to the horizontal one. Owing to the complicated construction of such aerials these experiments were not continued. But I hope that they will be taken up within a short time and that we shall then be thoroughly informed about all the different types of broadcasting antennas.

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CORRELATION OF DIRECTIONAL OBSERVATIONS OF ATMOSPHERICS WITH WEATHER PHENOMENA*

By
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Introduction

Since March, 1928, observations of the direction of arrival of atmospherics have been made by the American Telephone and Telegraph Company at Houlton, Maine, U. S. A. using a cathode ray direction finder.[1] This apparatus as used at Houlton has been described by Mr. A. E. Harper[2] in a paper in which the results of the observations are analyzed by means of long-period averages, and compared with data on the distribution of thunderstorms over the earth. It is the purpose of the present paper to point out the relation of individual observations to the weather conditions existing at the time, and to indicate the possible usefulness of such observations in weather forecasting.

Attempts have been made to correlate these observations with weather phenomena using the daily weather maps of the U. S. Weather Bureau and of the British Air Ministry, together with daily reports of thunderstorms in the United States, the latter kindly furnished by Dr. Kimball of the New York Office of the U. S. Weather Bureau. No detailed analysis of the results is presented in this paper, but our general conclusions are stated and illustrative examples given.

This work had as its inspiration similar observations made during the summer of 1927 by R. A. Watson Watt[3] and his associates in England and Scotland, with the assistance of the British General Post Office. In the case of the British observations, the use of two observing stations (one at Cupar, Scotland, the other at Slough, near London) connected by a telephone line made possible the identification of individual disturbances and the location of their origins by

* Dewey decimal classification: R 114. Original manuscript received by the Institute, March 29, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] R. A. Watson Watt and J. F. Herd, "An Instantaneous Direct-Reading Radiogoniometer," *Jour.* I.E.E., **64**, No. 353; May, 1926.

[2] A. E. Harper, "Some Measurements of the Directional Distribution of Static," presented at the meeting of the American Section of the U.R.S.I., Washington, D. C., May 15, 1929.

[3] Reported by Appleton at the Washington meeting of the U.R.S.I. in 1927.

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triangulation. It was found that in the vast majority of cases the locations coincided with those where thunderstorms were known to have occurred or where conditions were such that thunderstorms would be expected. The southeasterly edges of low-pressure areas were found to be the most common sources of disturbances.

The work at Houlton has been handicapped by the fact that only a single observing station was available, making triangulation impossible. Another difficulty which we encountered was due to the bidirectional ambiguity of the device, but this was removed by the installation of a unidirectional feature.

Correlation With Weather Conditions

In spite of these handicaps, it has been possible to correlate the observations with weather conditions in the vast majority of cases, excepting, of course, those occasions when the sources of atmospherics were in regions not covered by available weather data. In many cases the directions from which atmospherics came coincided with the bearings from Houlton of places where thunderstorms were reported. In many others the sources of atmospherics were apparently low-pressure areas where thunderstorms may have occurred, though none was observed at Weather Bureau stations. We are inclined to believe from these results, as well as from the work of others, that most atmospherics are due to lightning discharges, although, of course, the evidence is too incomplete to permit us to draw positive conclusions.

A low-pressure area seems to produce more atmospherics when it is moving rapidly. When it is more or less stationary and quiescent it produces few atmospherics. In the summer, lows produce many more atmospherics when over land than after they pass out to sea, but in cool weather the reverse is sometimes true. In the winter, sources as far away as Texas, the West Indies, South America, and Africa can be observed, but in the summer the effects of nearby disturbances usually overshadow these distant sources. On days when there is nearly a complete absence of thunderstorms in the United States, the atmospherics are generally light, unless there is a source due to a low not far out in the Atlantic.

Another interesting phase of the work has been that in which it has been possible to detect the approach of storms from areas not covered by available weather data. In one case, a distinct source of atmospherics gave evidence of a disturbance in the Caribbean beyond the southern limit of the U. S. Weather maps two days before this storm, moving northward, began to be indicated on the maps. In another case, a strong disturbance was indicated to the northwest of

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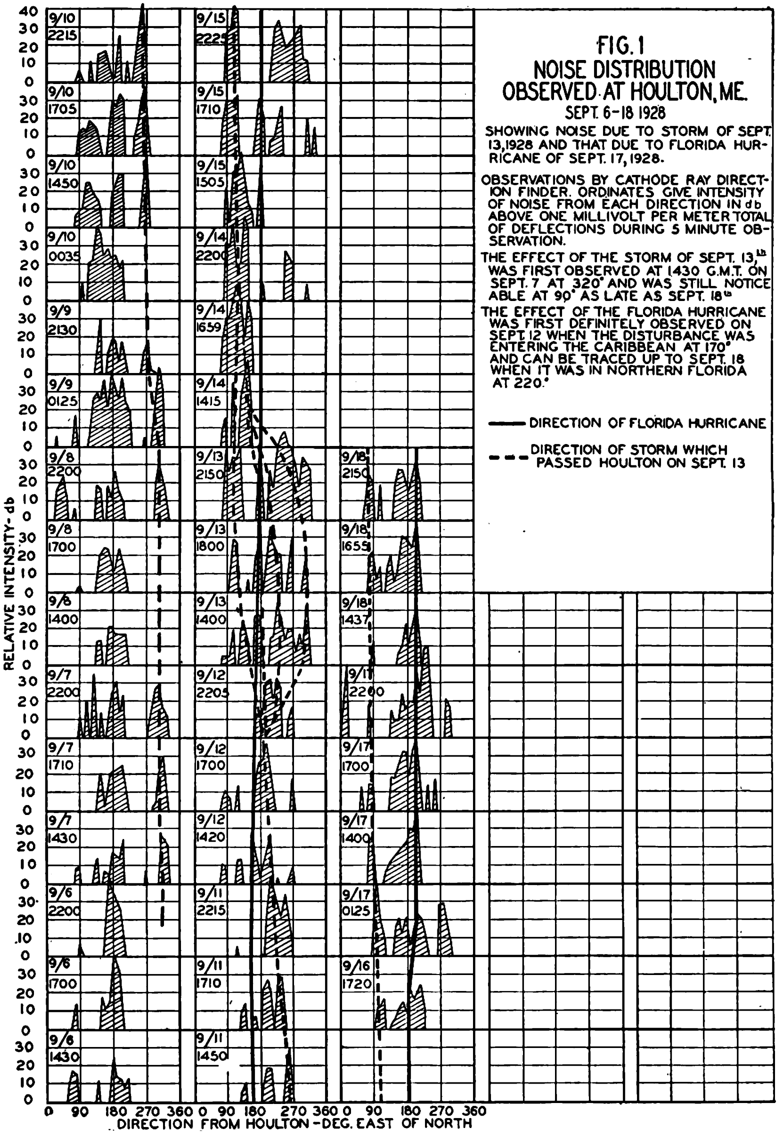

Fig. 1—Noise Distribution Observed at Houlton, Maine, September 6–18 1928.

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Houlton, the origin of which remained a mystery to us until the British Air Ministry weather maps were received some ten days later, which showed a low-pressure area over the Hudson Bay region.

We often have evidences of disturbances out to sea in the direction southeast from Houlton, which may be due to storms at sea which are not reported to the Weather Bureau.

To give an example of the way in which storms may be followed, by means of the directional observation of atmospherics, Fig. 1 has been prepared. This figure shows the directional distribution of atmospherics as observed at Houlton from September 6 to September 18,

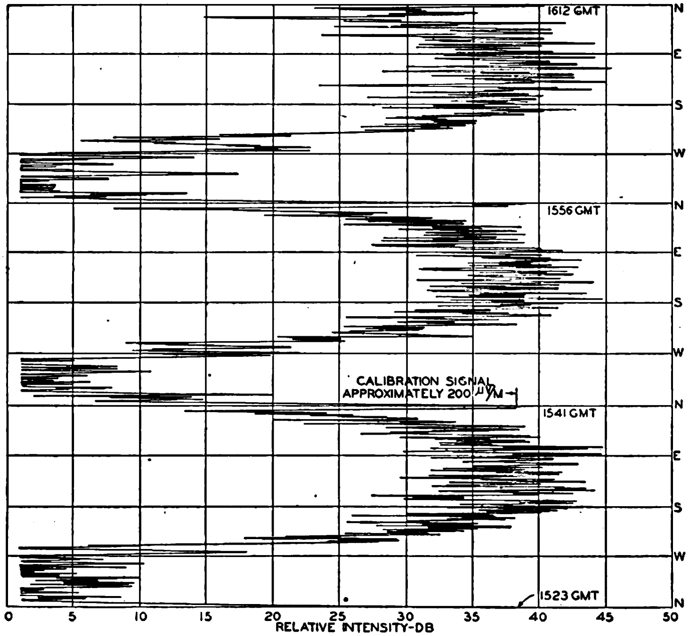

Fig. 2—Record of Rotating Recorder Taken from 1523 to 1612 G.M.T., September 14, 1928.

1928. During this period there were, of course, several storm centers causing disturbances, of which two have been selected for discussion. One is a storm which first gave us evidence of its existence on September 7, 1928, when it was somewhere northwest of the Great Lakes, bearing 320 degrees from Houlton. Starting at the lower end of the left-hand column and proceeding upward to the top of the drawing, thence up the second and third columns, the dashed line indicates the progress of the storm in terms of its bearing from Houlton. In nearly every observation, distinct evidence of the storm is seen in the form of

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a peak on the atmospheric direction curve in the direction of the storm. High winds and severe electrical disturbances accompanied the storm at several points along its course. It passed the vicinity of Houlton on September 13, 1928, being accompanied by unusually frequent lightning. The observations of that day showed the disturbance apparently surrounding Houlton, with atmospherics coming from several directions. On the next day (September 14) the disturbance was out to sea to the southeast of Houlton. Evidence of the storm at sea persisted for several days thereafter.

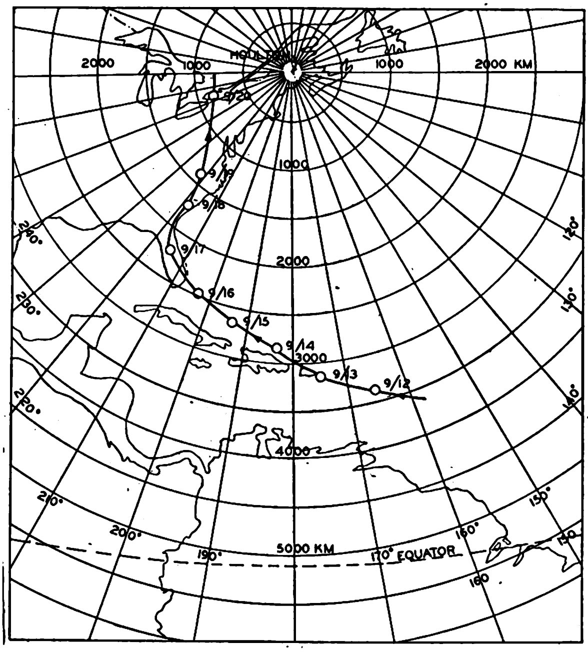

Fig. 3—Polar Map About Houlton, Maine, Showing Path of Hurricane September 12–20, 1928.

As an example of the results obtained from another method of atmospheric direction-finding, there is shown in Fig. 2 the record of an automatic recorder,[2] which shows evidence of this storm when it was southeast of Houlton on September 14, 1928.

The other storm selected for discussion is the Florida hurricane of September 10-20, 1928. The first definite indication of this storm from weather data seems to be on September 10, 1928, when it was reported southeast of Porto Rico, bearing about 150 degrees from Houlton. While there are some evidences of it in the atmospheric records

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prior to that date, one cannot establish a definite correlation due to the meagerness of the available weather data. The track of this hurricane is shown in Fig. 3, the data for which was obtained from the U. S. Weather Bureau.[4]

Starting from the bottom of the second column on Fig. 1, the solid line shows the progress of the hurricane, in terms of its bearing from Houlton, from September 11 till September 18, 1928. Although many other stronger disturbances are indicated, due to sources nearer Houlton, in most of the observations there is a definite peak in the direction of the hurricane. On September 14, the absence of evidence of the hurricane in the observations at 1400 and 1700 G. M. T. is probably due to the extremely strong nearby source, which made it necessary to reduce the amplification of the cathode ray device until the atmospherics due to the hurricane were not observable.

Advantages of Cathode Ray Apparatus over Rotating Loop

The use of radio direction finders as a means of locating storms is by no means new. In this country, however, previous workers have used automatic recorders associated with continuously rotating loop or loop-and-vertical antenna systems.[5] Such apparatus is subject to the limitation that it records only the integrated effect of all sources of atmospherics. In case two or more equally strong sources are present it is usually impossible to determine the direction of any of them, and weak sources cannot be detected when a strong source is present. This is quite a disadvantage from the point of view of weather forecasting, since atmospherics from a storm receding from an observing station will often mask those from an approaching storm concerning which information is desired. A comparison of Figs. 1 and 2 will illustrate this point by showing how impossible it would be to detect the atmospherics due to the Florida hurricane on the record of Fig. 2. The cathode ray direction finder, on the contrary, permits the determination of the directions of a large number of sources simultaneously, since the effect of each atmospheric is to produce a discrete deflection of the spot on the tube. Truly simultaneous atmospherics are so infrequent that they offer only slight hindrance in observing each source by itself.

[4] C. L. Mitchell, "The West Indian Hurricane of September 10–20, 1928." *Monthly Weather Review*, **56**, No. 9; September, 1928.

[5] E. H. Kincaid, U.S.N. "Two Contrasting Examples Wherein Radio Reception was Affected by a Meteorological Condition," Proc. I.R.E. **15**, No. 10; October, 1927. Includes summary of previous publications on this subject.

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The cathode ray apparatus is also very well adapted to triangulation. If two or more stations are connected by telephone, the observers can identify the deflections produced by each atmospheric, thus obtaining simultaneous bearings which can be used to plot the locations of the several sources. The results of Watson Watt's work in Great Britain using a telephone connection between observation points have demonstrated beyond doubt that triangulation is practicable.

Application to Weather Forecasting

To one who is without a detailed knowledge of the meteorology of weather forecasting this work raises a question as to whether a system of observing stations with cathode ray direction finders connected by telephone and telegraph would be of assistance in tracing the movements of storms. This question arises particularly in the case of storms out at sea or in areas where there are few or no weather observation stations.

It would seem that as few as three stations, one on the north Atlantic coast, one on the south Atlantic coast, and one in the middle west, would cover the eastern part of North America and the western part of the Atlantic Ocean fairly well. Our experience indicates that such a system might be helpful in the location of storms in Northern Canada, the Atlantic, the Gulf of Mexico, and the West Indies, as well as those in the eastern half of the United States. A similar system on the Pacific coast might permit the location of storms in the Pacific Ocean and possibly the forecasting of their arrival at the coast.

Conclusions

Our work at Houlton with the cathode ray direction finder has confirmed the results of Watson Watt and others in Europe in establishing a close connection between atmospherics and weather conditions. It has been possible in many cases to follow the movements of storms as far as 2000 miles from Houlton. Sources of atmospherics usually seem to be associated with the advancing edges of low-pressure areas. In the case of lows in the Northern Hemisphere moving from west to east, the southeastern part of the low produces the most atmospherics.

The cathode ray direction finder is particularly suitable for such work, since it permits the directions of several simultaneously active sources to be determined. By triangulation the locations of the sources can be established.

The question is raised as to whether a system of stations for the directional observation of static would be of assistance in weather forecasting, especially in following the progress of storms in regions where there are no stations for weather observations.

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EXPERIMENTS IN RECORDING RADIO SIGNAL INTENSITY*

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Summary—*The paper describes briefly the method of recording the strength of long-wave radio signals used at the Bureau of Standards and gives some of the results obtained. The curves shown indicate the great variability of the wave propagation both in regard to strength and the angle of incidence of the downcoming wave. This variability appears to be greater for transmission distances below 1000 km than for greater distances. An apparent connection is shown in certain cases between the night signal variations and magnetic storms. The observations seem to indicate that the downcoming waves are reflected (or refracted) from rapidly changing masses of ionized gas.*

It was originally thought that daylight observations represented normal radio transmission, while night observations showed the normal transmission disturbed by reflection effects, the study of which might be properly neglected until the simpler daylight conditions were better understood. In recent years, however, it has become increasingly evident that daylight and night transmission phenomena are so interconnected that there can be no clear understanding of the first without considering the second. Therefore, as our laboratory personnel was too limited to permit night watches, it was decided to try automatic recording. Our apparatus has been described by my assistant, Mr. Judson, in another place.[1] It consisted briefly of an autodyne detector such as we have long used for daylight measurements by the telephone comparator method,[2] and several stages of audio-frequency amplification. The last audio-freqeuncy stage is coupled inductively to a tube rectifier circuit containing the Cambridge recorder, which prints the deflections on a revolving drum every half minute. By means of a clock relay, described in Mr. Judson's article, different stations can be tuned in or the circuit can be connected to different signal collector systems as may be necessary for the different records desired.

Automatic recording has some bad as well as good features. While it gives easily a vast number of series of observations, it is somewhat

* Dewey decimal classification: R 270. Original manuscript received by the Institute, April 13, 1929. Read at Brussels meeting of the U. R. S. I., September, 1928. Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Proc. I. R. E., **16**, 666; May, 1928.

[2] Proc. I. R. E., **12**, 521; October, 1924.

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limited in its accuracy and dependability as compared with the work of personal observers. For example, unknown disturbances may at times intrude themselves and not be detected, and accidents may happen to the apparatus rendering a whole night's work useless.

Until the time comes when special transmitting stations are operated purely for experimental purposes, continuous records, continued day after day for months at a time, can evidently be made only on regular traffic from commercial transmitting stations. This, of course, rules out all extended experiments depending on special signals. Commercial stations are more or less irregular, seldom sending much on Saturday nights or on Sundays, and sometimes closing down entirely for considerable periods.

The particular system of recording which we have adopted has certain good points which deserve mention. By using only audio-frequency amplification a very good degree of constancy of calibration can be obtained over periods of many months. If the filament currents of the amplifier are kept constant within ± 1.5 per cent and the plate voltages within about ± 10 per cent, the changes in sensitivity will not be greater than ± 10 per cent, which is about the limit of accuracy in measuring absolute signal intensity from commercial sending.

Another convenient fact is found to be that it is quite possible with this type of recorder to get a nearly linear relationship between the antenna voltage and the recorder deflection over most of the scale.

It is also found that when an interfering signal is weaker than the signal being measured the two effects do not appear to superpose on the recorder within the limits of accuracy assumed above, i. e., the resulting deflection seems to correspond closely to that of the stronger signal alone. It is only when two signals are nearly equal in intensity that superposition becomes evident.

Some of the work which is being done by means of automatic recording is described below.

Reception Variation

The recorder was first used for registering the general changes in long-wave signal intensity during the day and night. In the beginning an attempt was made to measure a large number of stations, observing each station for five minutes in every hour. Curves of this kind were shown in Mr. Judson's paper already cited. While this method was fairly satisfactory, at least with distant stations, it was soon decided that, on account of the rapid changes in intensity, more frequent observations on each station were desirable. In recording the trans-

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oceanic long-wave stations, with which our work largely deals, it was found, especially in the cases of stations at distances of less than 1000 km, that the sequences of change in intensity showed very great variability on different nights. The degree of this variability may be seen in the collection of curves in Fig. 1. In this figure the curves are made up from series of ten recorder points taken each half minute with five-minute intervals after each series. In considering the variability of the curves without going into the possible causes of variations, we see at once that curves taken on single nights, or even on a considerable number of nights, would have very little value for purposes of generalization. It was thought at first that there were more or less

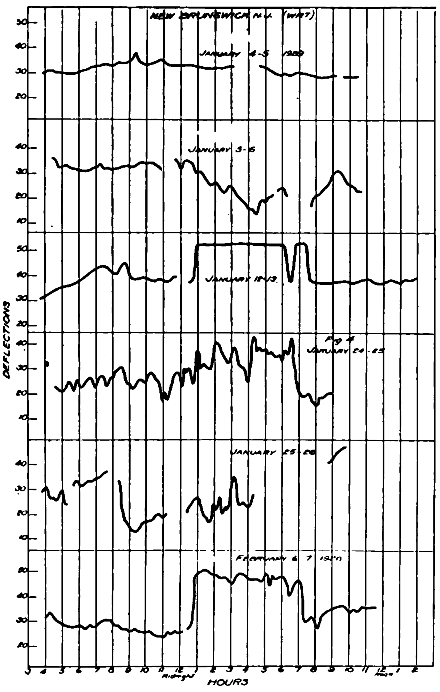

Fig. 1

periodic cycles of night change, the same patterns of change repeating themselves every two or three weeks, but we are now doubtful as to the existence of such cycles, apart from the possible effects of magnetic and solar disturbances.

Fig. 2 shows the differences which may exist in the night changes in signals of somewhat different wavelengths coming along the same path at the same time. The two stations, WCI ($\lambda = 16350$ m, $f = 18.35$ kc)

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and WGG, ($\lambda = 13500$ m, $f = 22.22$ kc), are both at Tuckerton, N. J., 251 m from Washington, WCI transmitting from an umbrella antenna while WGG makes use of a flat top antenna. It is not believed, however, that the differences observed are produced by the antenna forms, as similar differences are also found in other cases where the antennas are of the same type.

In the case of transmission over distances short enough to make the ground wave comparable in intensity with the downcoming wave, it must be remembered that the phase relation between the two, due to the difference in length of their paths, is probably the chief factor in determining whether the signal intensities at night rise above or fall below their daylight values. This fact must be remembered in making

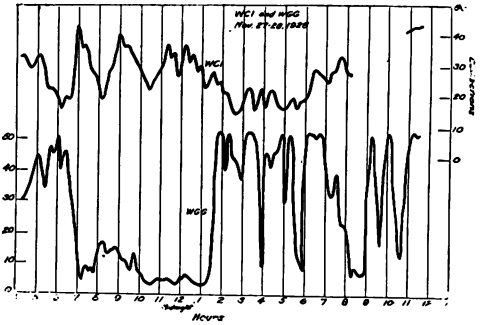

Fig. 2

use of the night signals from stations with strong ground waves for the study of the correlation of radio transmission with other natural phenomena.

It is generally believed that below the Kennelly-Heaviside layer there is a region of sufficiently great ionization to produce absorption in the downcoming wave, certainly in the day time and perhaps, in a lesser degree, at night. The relative importance of reflection or refraction in the Kennelly-Heaviside layer, and absorption in the absorbing layer in affecting signal intensity is not yet by any means clear, the absorption perhaps being more important in the day time, and the changes in reflection at night.

Measurement of Downcoming Wave Angle

Another use for the automatic recorder is the continuous determination of the angle with the horizontal at which the downcoming wave reaches the receiving station. A method for calculating this from observations made on a vertical antenna and on a loop antenna has been given by Appleton and Barnett.[3]

[3] *Proc.* Royal Soc., (A), **109**, 621, 1925.

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In the following explanation, for the sake of the clearness of the physical picture, the electric field is considered both in the case of the antenna and of the loop, instead of considering the electric field in the case of the antenna and the magnetic field in the case of the loop, as in the paper by Appleton and Barnett.

Suppose the case of a radio wave passing along the ground with its electric force E_G vertical and a reflected or refracted wave from the same source coming down from the Kennelly-Heaviside layer at an angle ϕ with the horizontal and with its electric force E_R at right angles to the direction of propagation and in the propagation plane. E_R on account of the difference in length of the two paths will, in general, be out of phase with E_G.

From Fig. 3A, it is seen that the downcoming wave E_R before and after reflection from the earth will have its vertical components $E_R \cos \phi$ and $E_{R1} \cos \phi$ in phase but its horizontal components $E_R \sin \phi$ and $E_{R1} \sin \phi$ in opposite phase, so as to neutralize each other, if the earth is a perfect conductor, which is generally approximately the case for

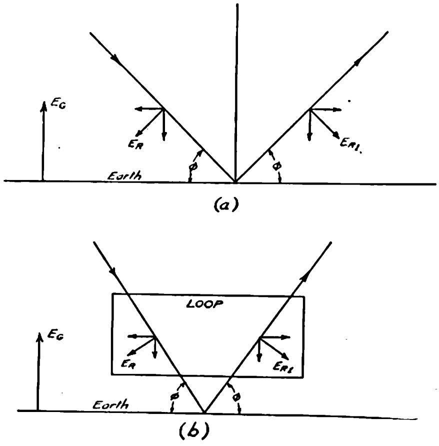

Fig. 3

very long waves. The resultant e. m. f., therefore, as measured on an antenna will be practically vertical and will be $2E_R h \cos \phi$ when h is the effective height of the antenna.

Different conditions prevail in the case of reception on a vertical loop with its plane in the plane of propagation, as has been shown by Appleton and Barnett in the paper cited. The loop current may be looked upon as due to the difference in phase of the wave where it enters the loop and where it leaves it, the resultant electromotive force being independent of the angle at which it strikes the loop and equal

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to $(E_R 2\pi nh')(l/\lambda)$ where E_R is the field strength; l, the distance from the front to the back of the loop in the direction of propagation; $nh'l$, the area turns of the loop; and $2\pi(l/\lambda)$, the difference in phase of the wave at the points of entering and leaving the loop. As the phase of the horizontal component will be shifted 180 deg. by reflection and as the reflected wave now passes the loop from below, (see Fig. 3B) the resulting e.m.f. produced in the loop by the reflected wave will be in the same direction as that due to the direct wave and the sum of the two e.m.f.'s will be $4\pi E_R nh'(l/\lambda)$. If we assume no abnormal polarization in the downcoming wave, and that the field due to the downcoming wave is negligible in comparison with the ground wave in the daytime, and that the latter remains of the same intensity by night as by day, we may determine the angle of the downcoming wave as follows: having observed the average day field intensity (ground wave alone) E_G, which will be the same for the antenna and loop, and then the average night field intensities on the antenna and loop, which will, in general, be different, we have, calling the resultant antenna field intensity E and the loop field intensity E'

Antenna	Loop
E_D (day) $= E_G$	E_D' (day) $= E_G$
E_N (night) $= E_G + 2KE_R \cos\phi$	E_N' (night) $= E_G + 2KE_R$

The difference in night and day field intensities is then

$$E_N - E_G = 2KE_R \cos\phi \qquad\qquad E_N' - E_D = 2KE_R$$

The ratio of the night and day difference of the field intensities of the antenna and loop is

$$\frac{2KE_R \cos\phi}{2KE_R} = \cos\phi$$

where ϕ is the angle which the direction of the downcoming wave makes with the horizontal, and K a factor depending on the integral phase difference between E_G and E_R.

The accuracy of this result will be vitiated to the extent that reflection takes part in day transmission and to the extent that the ground wave varies between night and day.

Fig. 4 shows the great differences which are found in the loop and antenna reception patterns from long-wave stations at night, corresponding to differences in the angle of the downcoming wave. The reception shown in the figure is from WSS at Rocky Point, L. I., the distance from Washington being 435 km, and the wavelength 16100 m. Since the curves of the individual days are so varied in form, an attempt

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has been made to use averages covering a month for determining the mean values of the downcoming wave angles at the various times of the night. It has not been found possible to determine the angle of the downcoming waves in the middle of the day, although these waves almost certainly exist, at least in winter, as is shown by the fact that the signals sometimes reach two or three times their calculated values. Their presence has also been indicated by the work of Hollingworth.[4]

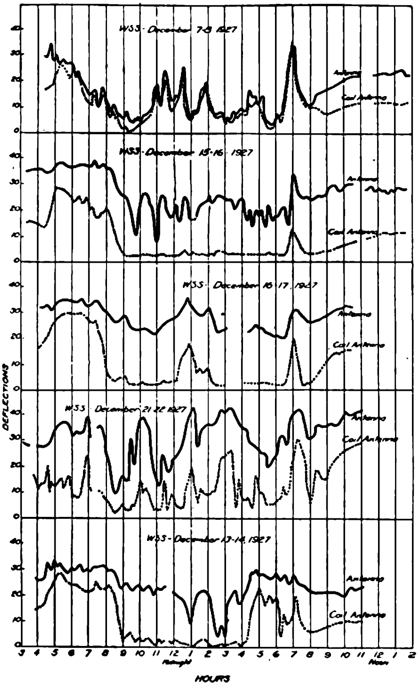

Fig. 4

Fig. 5 shows the curves of the mean values of the angle for the hours between 4 P. M. and 10 A. M. for the station WSS in the months of December 1927 and February 1928. The two curves show a rapid rise in angle about sunset, an irregular course during the night, a fall followed by a rise about sunrise, and a rapid fall to low values an hour or two later.

Attempted Determination of the Height of the Kennelly-Heaviside Layer

If it were possible to assume that the downcoming wave is the result of regular reflection from a plane surface we could at once cal-

[4] *Jour*. I. E. E., London, 64, 579, 1926.

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culate the height of the reflecting layer since the distance between the sending and receiving stations is known. Fig. 6 shows the average

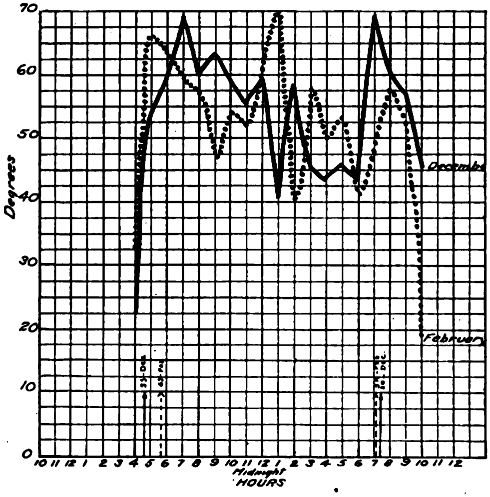

Fig. 5

heights for the various hours of the night, for the station WSS during the month of February 1928, as calculated from the downcoming wave

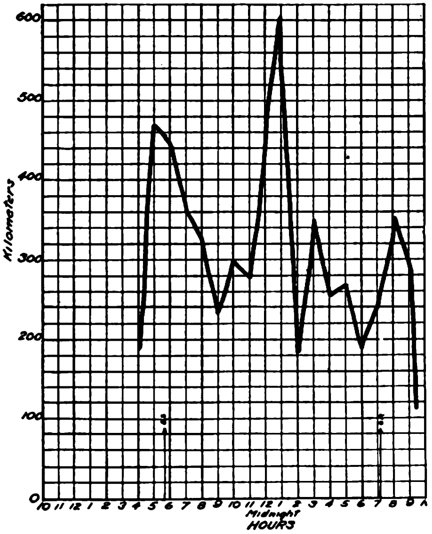

Fig. 6

angles in Fig. 5. Fig. 6 indicates a rapid rise in the height of the layer near the time of sunset, with irregular changes during the night and

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a fall after sunrise, corresponding to the changes of angle in Fig. 5. This is probably qualitatively correct, but an actual change in height from 50 to 500 km, as indicated in Fig. 6, would necessarily result in the intensity of the signal passing through a number of maxima and minima due to the interference of the ground and downcoming waves. These maxima and minima do not appear on the records of the recorder. If we consider the indicated height records of the individual nights, the heights calculated are seemingly preposterous, sometimes exceeding 2000 km.

In the examination of the individual daily curves of the loop and antenna reception from which Fig. 5 is derived, we find that the calculated angles of the downcoming waves are not only nearly always very large but in many cases appear to be greater than 90 deg., that is, the wave comes down from the back. These observations may be explained either by supposing that the downcoming wave is produced by reflection from a rough surface or perhaps from irregular ionized cloudlike masses, or by refraction in a medium of very irregularly distributed ionization.

Nature of the Fields

It may be of interest to study briefly the variations in the downcoming wave which would produce the changes on the antenna and loop which the observations indicate. This may be done with the help of the diagrams of Fig. 7. In these the antenna and loop are shown with the vertical and horizontal components of the electric fields acting on them. Here E_G represents the field of the ground wave assumed to be constant day and night, $E_R \cos \phi$ the vertical component of the field of the downcoming wave, and $E_R \sin \phi$ the horizontal component of the field of the downcoming wave.

We assume that the vertical antenna is affected only by the vertical electric fields, E_G and $E_R \cos \phi$, while the loop with its plane in the plane of propagation is affected by the total field of each wave of its angle of incidence. The effects of the reflection from the earth have been already explained in the discussion of the calculation of the angle of the downcoming wave, and it should be remembered that two waves passing across the loop in opposite directions produce loop currents in opposite directions.

For simplicity, in the diagrams of Fig. 7 E_R and E_G are considered either to be in phase or in opposite phase. The legends placed beside the diagrams will probably furnish sufficient explanations of the combinations of electric fields and the resulting changes in the antenna and loop signal intensity. All of the cases of change in antenna and loop signal intensities given have been identified in our records.

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Long-Wave Night Signals and Magnetic Storms

The continuous records of the long-wave signals promise more complete information concerning the relation of magnetic storms to the variations in radio transmission at these wavelengths than it has been possible to obtain from the daylight observations, which were the only ones taken regularly at the Bureau of Standards before the introduction of the recorder.

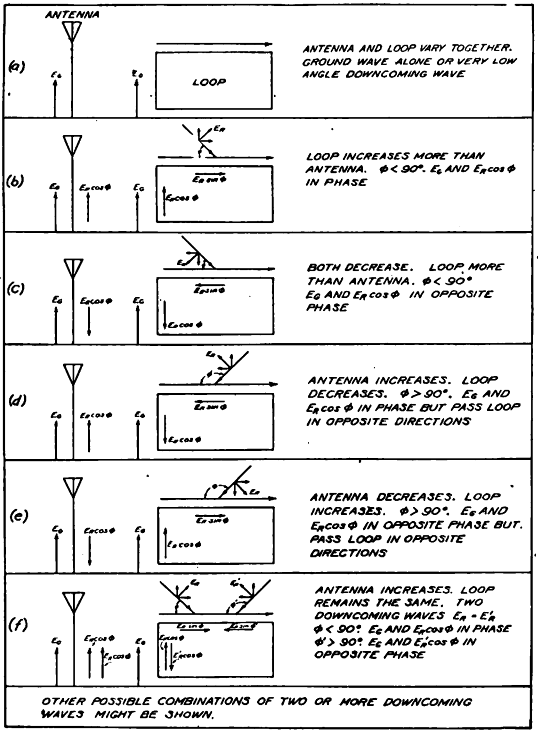

Fig. 7

Some records taken on signals from the R.C.A. station WCI at Tuckerton, N. J., wavelength 16750 m, (frequency 17.91 kc) in July 1928, are shown in Fig. 8. These include the period of the unusually severe magnetic storm of the night of July 7–8 and show apparently unmistakable evidence of the effects of this storm on the transmission. As no record was obtained at the Bureau of Standards on the night of the storm, G. W. Pickard has kindly permitted me to use one taken by him at Newton Center, Mass., where the curves of WCI generally agree closely in behavior with those taken in Washington. This curve is shown as a dotted line in the figure. It will be noted that if we compare

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the average curve of the three days before the storm, which we believe represents normal comparatively undisturbed summer conditions, with the curve of the night of the storm and those of the nights which follow, the storm appears to have caused an inversion of the general night trend, changing the slight normal drop during the night to a considerable rise. During the hours of the continuation of the storm, from 6:30 P.M. on the 7th to 6 A.M. on the 8th, the night curve is not only in general much higher than usual but very much disturbed. On the succeeding nights the irregularities of propagation gradually became less until on the night of the 12th–13th almost normal conditions had

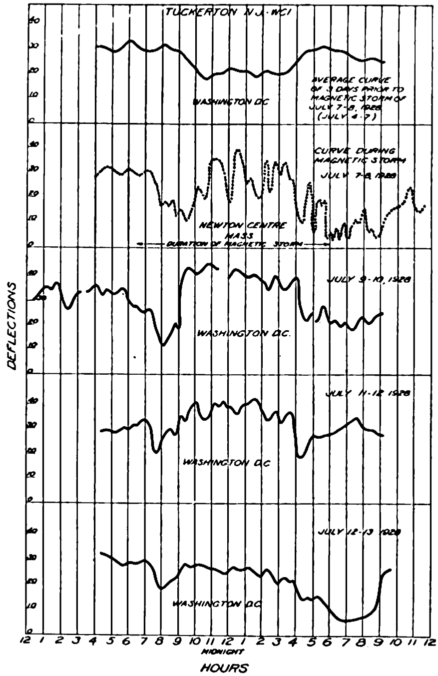

Fig. 8

returned. Similar effects have been observed in the case of two other major magnetic storms on the signals of WCI, and irregularities have often been detected due to the minor storms noted as No. 1 days in the magnetic reports.

WCI appears to be particularly suited in wavelength and in distance from Washington for showing the effects of magnetic disturbances on the night signals. Some of the other R.C.A. stations in New Jersey and on Long Island show these effects much less. These differ-

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ences in behavior are perhaps to be expected when we remember that the increase or decrease of the night signal depends so much on the phase relations of the ground and downcoming waves.

Unidirectional System

Automatic recording is also applicable to a method of reception which was first introduced by Appleton and Ratcliffe,[5] for the study of downcoming waves and which was independently used for the same purpose a little later at the Bureau of Standards.

In this method the well known combination of a loop with a vertical antenna for the elimination of signals from a given direction in the horizontal plane takes the form of a cardioid.

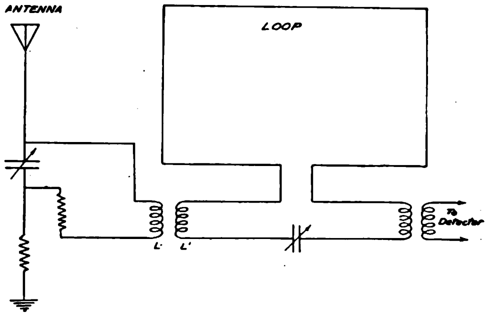

Fig. 9

This circuit, often called the barrage circuit in America, has long been used for the elimination of undesired signals and for the reduction of atmospherics. The circuit arrangement is shown in Fig. 9. Here the loop is turned on its vertical axis so that its plane is in the plane of propagation, but is so coupled to the antenna that the reception from the given direction on the loop opposes that on the antenna. Then the strength of coupling LL' is adjusted so that in the middle of the day, when it is assumed that only the vertical ground wave is present, the two receptions balance and no deflection is shown on the recorder. If these conditions are fulfilled, the system is balanced for all vertical fields of the given frequency from the given direction for which the adjustment was made. If, however, as sunset approaches, or during the night, downcoming waves appear, their horizontal components of field will destroy the balance and deflections will be produced.

Calling E_G the electric component of the field due to the ground wave and E_R that due to the downcoming wave, the effect of the an-

[5] *Proc.* Roy. Soc., (A), **115**, 291, 1927.

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tenna on the receiver is proportional to $E_G+KE_R \cos \phi$, and of the loop E_G+KE_R as was shown in the discussion of the angle of the down-coming wave. Since the loop and antenna are adjusted so as to produce equal and opposite effects on the receiver in the case of the reception of the ground wave, the resultant effect on the receiver when down-coming waves occur is

$$E=A(E_G+KE_R-E_G-KE_R \cos \phi)$$
$$=AKE_R(1-\cos \phi)=2AKE_R \sin^2 \frac{\phi}{2}$$

where A is a constant.

The advantage of this system over that in which the antenna and loop are used separately is that here we are able to study the down-coming wave free from the ground wave although modified by K, the factor due to the phase difference between E_G and E_R.

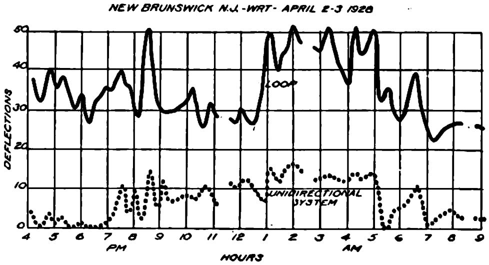

Fig. 10

Fig. 10 shows two curves of reception of the R.C.A. station WRT ($\lambda=13200$ m, $f=22.73$ kc) at New Brunswick, N. J., as recorded in Washington on the night of April 2–3, 1928. The solid curve represents reception on the loop and the dotted curve that on the unidirectional system. The sensitivity of the recorder when used with the unidirectional system was four times as great as when used with the loop. It will be noticed that the variations in the two curves generally, but not always, follow each other.

Our knowledge of the conditions in the upper atmosphere which affect the radio waves as they pass through it to the receiving station is still very fragmentary.

The impression which is gathered from the large number of records of reception at wavelengths above 10,000 m, taken on the automatic recorder, does not by any means support the view that the bending of the waves in the upper regions is due to any approximately regular reflection or refraction.

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The somewhat confused picture which we have gained is rather that of rapidly changing masses of ionized gas forming an irregular and shifting lower surface and possibly at times thinning out or forming openings so that the rays may then pass to higher levels before being turned back toward the earth.

There is, however, a difficulty in accepting this conception of reflection from an irregular changing surface, as it would seem to imply rays striking the receiving system at times from the side that is not in the great circle plane joining the sending and receiving stations. Such rays would produce deviations in direction finding of a type which according to the experiments of Smith-Rose[6] with the Adcock direction finder should not exist.

[6] Proc. I. R. E., **17**, 467; March, 1929.

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THE RELATION OF RADIO PROPAGATION TO DISTURBANCES IN TERRESTRIAL MAGNETISM*

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Summary—*This paper presents the results of a study of an apparent inter-relationship between radio reception and changes in the earth's magnetism. The results show that for long-wave daylight reception over great distances 4,000 to 7,100 km) there is in general a variable but definite increase in the intensity of the received signal following the height of severe magnetic disturbance. This increase reaches its maximum in from one to two days and disappears in from four to five days. For moderate distances (250 to 450 km) there is an increase in the intensity of the received signal noticeable before as well as after the magnetic storm reaches a maximum. These changes in intensity cover periods from two to four days both before and after the magnetic storm reaches its height.*

In a paper presented before the Institute of Radio Engineers in May, 1925, Espenschied, Anderson, and Bailey[1] pointed out that at times of severe magnetic storms abnormal radio transmission was likely to occur, night field intensities being greatly reduced and daylight intensities slightly increased. These conclusions were based upon hourly observations (for one day a week) of low-frequency transmission (17, 25, and 57 kc) across the Atlantic covering a period of about two years. From a more exhaustive analysis of this same material with the addition of later observations Anderson[2] in 1928 concludes "High daylight radio field strengths (at 57 kc) obtain during periods of marked magnetic activity. In most cases, the magnetic disturbances precede the high values, but there is evidence of an abrupt rise to high values preceding the magnetic disturbance and at times a gradual rise to high values independent of the magnetic activity ..... It is seen that the high radio fields do not occur particularly on days of high magnetic character but rather during periods when magnetic storms occur. Because the radio data are available for one day a week only, no detailed conclusions can be drawn. For the most part,

* Dewey decimal classification: R 113.5. Original manuscript received by the Institute, February 5, 1929. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce. To be published in forthcoming issue of the Bureau of Standards Journal of Research.

[1] Espenschied, Anderson and Bailey, *Bell Sys. Tech. Jour.*, **13**, No. 3, 1925. Proc. I. R. E., **14**, 7; February, 1926.

[2] C. N. Anderson, Proc. I. R. E., **16**, 297; March, 1928.

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however, the high fields follow the magnetic disturbance and then gradually fall off."

Pickard[3] from a series of observations on broadcast reception taken at Newton Center, Mass., on the Chicago station WBBM (800–900 kc) concludes that the "depression of night reception accompanying magnetic storms is very striking. Day reception from Nauen, AGS, (24 kc) shows an inverse effect, an increase of field accompanying and following the storm."

In a paper[4] presented before a meeting of the International Union of Scientific Radio Telegraphy in Washington, October, 1927, it was pointed out that the field intensity of the American station WSS (18.5 kc) for the duration of 8 months when averaged in periods of

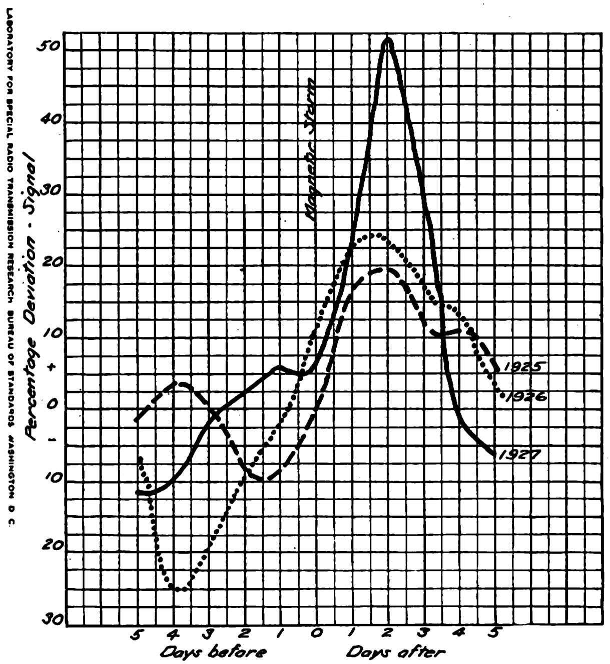

Fig. 1—Average daily deviation from the monthly mean of daylight field strength of signal from stations in Europe (LY, FU, AGW, GBR) during the progress of magnetic storms; 1925, 1926, 1927.

five days, exhibited a marked tendency to vary with the diurnal range of horizontal intensity of the earth's magnitic field. This indicated the possibility of a day by day relationship between magnetic disturbances and variations in signal strength. The present study was, therefore,

[3] G. W. Pickard, Proc. I. R. E., 15, 83, February, 1927; also 749, September, 1927; and 1004, December, 1927.
[4] L. W. Austin and I. J. Wymore, Proc. I. R. E., 16, 166; February, 1928.

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undertaken to determine whether such a correlation existed. A long series of reception data consisting of daily observations on low-frequency stations (15 to 23.4 kc) was available, which was particularly suitable for this investigation. These measurements had been made at the Bureau of Standards by the telephone current comparator method.[5] Field intensity measurements from two groups of stations were examined; those made on signals from long distances, (4000–7100 km), and those on signals from moderate distances (less than 500 km). For the former, observations taken from 10 to 11 A. M. on Lafayette (LY), Ste. Assise (FU and FT), Nauen (AGSandAGW), Rugby(GBR), Coltano (ICC), and Bolinas (KET) were utilized and for the latter, observations at 10 A.M. and 3 P.M. on the Radio Corporation stations

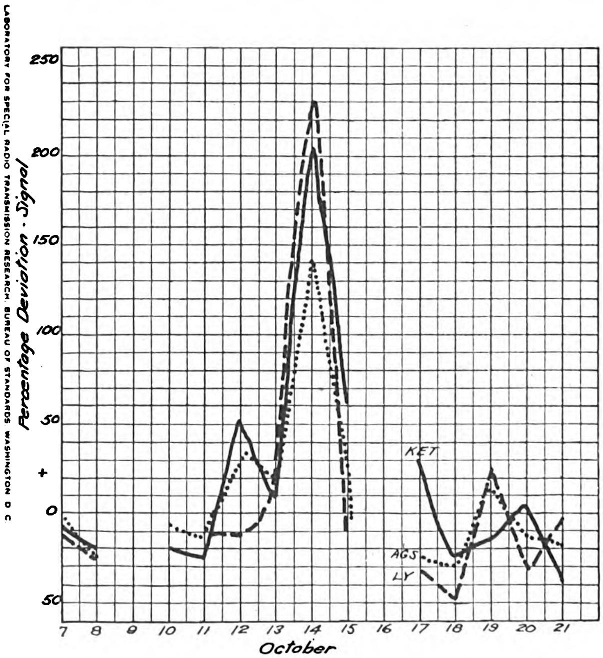

Fig. 2—Deviations in signal strength from the monthly average during the progress of the magnetic storm of October 12, 1927.

at Tuckerton, N. J. (WGG), New Brunswick, N. J. (WRT and WII), and Rocky Point, L. I. (WSS). In order to eliminate as much as possible any variations due to conditions not generally effective, stations of approximately the same wavelength were grouped and the data were averaged. Thus, in Fig. 1, LY (15.9 kc), FU (15.0 kc), AGW (16.5 kc)

[5] L. W. Austin and E. B. Judson, Proc. I. R. E., **12**, 521; October, 1924.

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and GBR (16.1 kc) are grouped together; in Fig. 3, AGS (23.4 kc), FT (20.8 kc), Bolinas KET (22.9 kc), and ICC (19.9 kc); and in Fig. 4, the Radio Corporation stations WII (21.8 kc), WGG (18.9 kc), WRT (22.7 kc), and WSS (18.7 kc).

The field intensity of low-frequency signals is believed to be less influenced by magnetic storms than that of the broadcast range. For this reason, only the most severe disturbances were considered in the calculations. Since practically all severe magnetic storms occur simultaneously over the earth the observations taken at the Cheltenham Magnetic Observatory of the U. S. Coast and Geodetic Survey were considered sufficiently indicative of changes in magnetic activity. As a qualitative measure of daily magnetic activity "magnetic character of day" numbers[6] were used to determine the occurrence of and to locate the central day of the magnetic storms which were selected in preparing the data in Figs. 1, 3, and 4 and the diurnal range of horizontal intensity of the earth's magnetic field was used for comparison in Figs. 5 and 6.

Days for which the magnetic character number was reported as 2 at Cheltenham, Md., were considered days of maximum magnetic activity and are represented by the zero point of the abscissas in Figs. 1, 3, and 4; i. e., they are the central days of eleven-day periods extending from five days before to five days after each magnetic storm. Averages were made of the radio field intensity of the stations on the corresponding days of these eleven-day periods.

The following table gives the dates of the magnetic storms considered in the calculations:

1925	1926	1927
Jan. 19–20	Jan. 26–27	March 28
May 4	Feb. 23–24	April 14
June 13	March 5	May 5
June 24	Apr. 14–16	July 21–22
July 26	May 4–5	Aug. 20–21
Aug. 22–23	June 1–2	Oct. 10
Sept. 1–2	Sept. 9	Oct. 12
Sept. 14–15	Sept. 15	Oct. 22–23
Sept. 21	Sept. 20–21	
Oct. 23–24	Oct. 14–16	
Nov. 9		

In Fig. 1 are given the daylight values of the percentage deviations from the corresponding monthly averages of signal intensity of the long-wave European stations (LY, FU, AGW, and GBR) during the time of greatly increased activity of the sun in the years 1925, 1926, and 1927. While the values for the curves are smoothed, they approximate closely the actual deviations obtained. The trend of the curves

[6] For a qualitative estimate of magnetic conditions days are commonly divided into three classes and designated as follows: 0 denotes days which are magnetically quiet; 1, moderately disturbed days; and 2, severely disturbed days.

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before the maximum of the magnetic storms varies somewhat in the three years although in general it tends to fall below the average. The most striking similarity is the high value on all the curves on the second day after the peaks of the storms. In connection with this, the behavior of signals at the time of one extremely severe disturbance, that of Oct. 12, 1927, is interesting. In Fig. 2 the percentage deviations from the monthly averages of field intensity for the stations, Lafayette (LY), Nauen (AGS), and Bolinas (KET), at the time of this storm are given. Intensities well above average were observed on October 12, the day of the maximum disturbance, but on October 14, two days

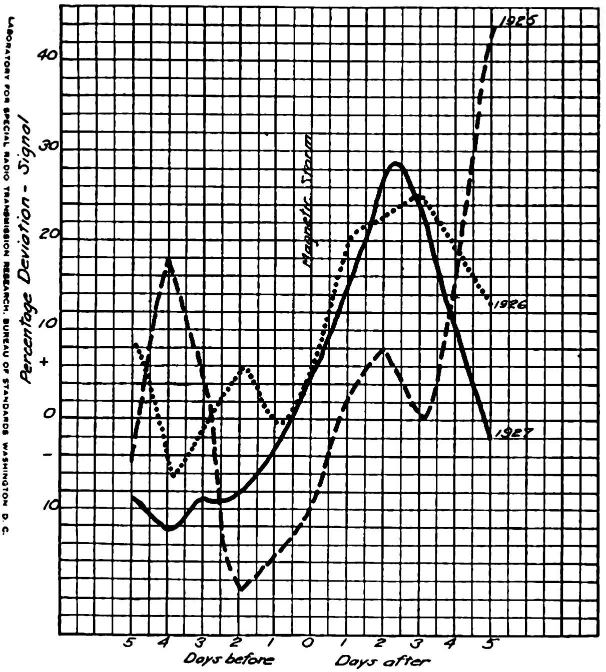

Fig. 3—Average daily deviation from the monthly mean of daylight field strength of signal from stations in Europe and California (FT, AGS, KET, ICC) during the progress of magnetic storms; 1925, 1926, 1927.

following, the intensity had increased so greatly that in some cases it was more than 200 per cent above the average value for the month. This increase in signal strength is too great to be a recovery from an abnormal condition before the storm and so probably represents some real effect of the condition productive of the magnetic disturbance.

In order to obtain some idea of the variation of signal strength on magnetically quiet days an average for each of three years was made for twelve days which were reported as magnetically quiet (magnetic

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character number = 0) and which were removed by five or more days from any reported disturbance. For 1925 these results gave an average signal deviation from the monthly average of two tenths of one per cent for quiet days; for 1926, six tenths of one per cent; and for 1927 one tenth of one per cent, the mean for the three years being three tenths of one per cent. Such an average, of course, represents merely the normal variations. Individual variations of field intensity on undisturbed days at times are much larger, and may occasionally reach or exceed 10 per cent.

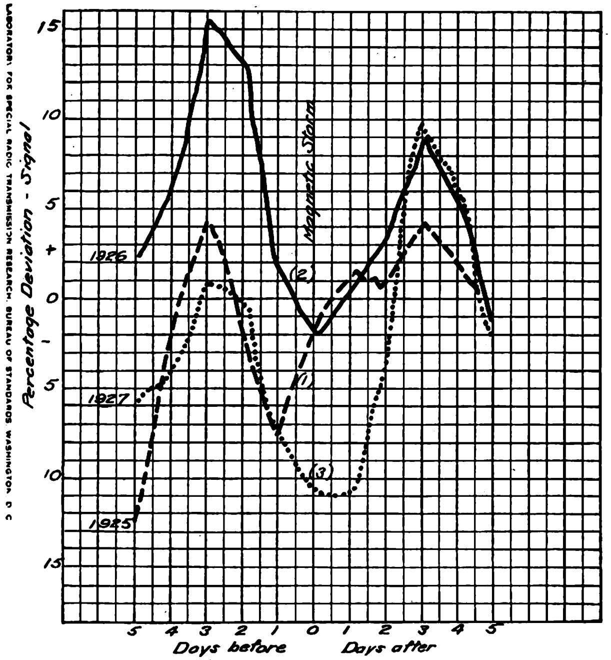

Fig. 4—Average daily deviation from the monthly mean of daylight field strength of signal from stations in New Jersey and Long Island during the progress of magnetic storms: (1) WII and WGG, 1925; (2) WII, WGG, and WSS, 1926; (3) WII, WGG, WSS, and WRT, 1927.

In Fig. 3 the average deviations from the monthly means for Nauen (AGS), Ste. Assise (FT), Bolinas (KET), and Coltano (ICC) for the same three years are given. The same general tendency is noted in these curves as in those of Fig. 1 with the exception that the curve for 1925 shows high values on both the fourth and fifth days after the maximum magnetic disturbance.

The observations of field intensities of American stations (WII, WGG, WRT, and WSS) at moderate distances gave somewhat different results. In general they show, for the same three years, a depression of signal strength below normal on the day of the storm, preceded

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three days before the storm by a considerable rise in intensity and followed three days after by another increase. The daily average deviations from the monthly averages during the periods of magnetic storms for 1925, 1926, and 1927 for these stations are shown in Fig. 4. Curve 1 gives the average of WII and WGG at 10 A.M. and 3 P.M., 1925; curve 2 of WII, WGG and WSS, at 10 A.M. and 3 P.M., 1926; and curve 3 an average of WII, WGG, WRT and WSS, at 10 A.M. for 1927.

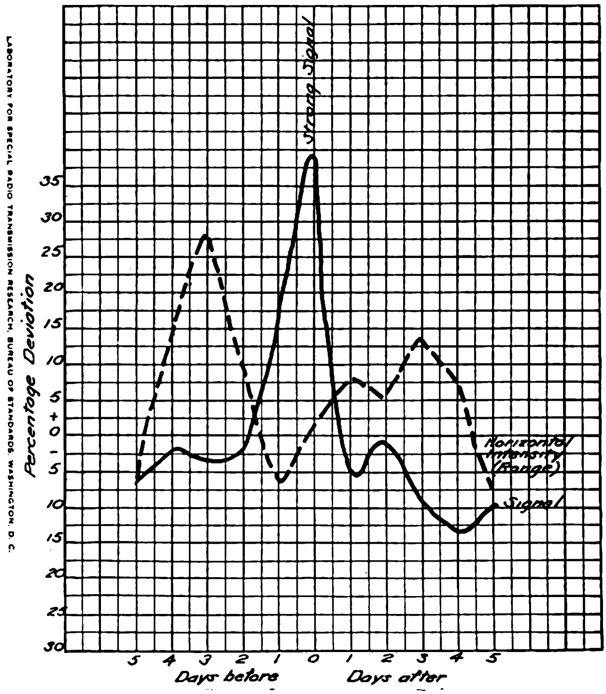

Fig. 5—Average daily deviation from the monthly mean of daylight field strength of signal (Rocky Point, WSS) and of horizontal intensity (range) of the earth's magnetic field, 1926.

A signal whose intensity is 25 per cent or more above the average for the month is considered well above normal and due to some unusual conditions effective along its path. In Fig. 5 a comparison is made between the variations in field intensities before and after these days of unusually strong signals and the diurnal range of the horizontal intensity of the earth's magnetic field. The center or zero day is taken as the day on which the observed field intensity was 25 per cent or more above the monthly average. In Fig. 5 the station observed was WSS, at 10 A. M., 1926; in Fig. 6, WII at 10 A.M., 1927. High values of the diurnal range occurred three days before and from two to three

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days after the signal peak. All data were smoothed by the formula

$$\frac{a+2b+c}{4}$$

From the foregoing curves it is evident that during periods of magnetic storms the behavior of low-frequency (15 to 24 kc) daylight

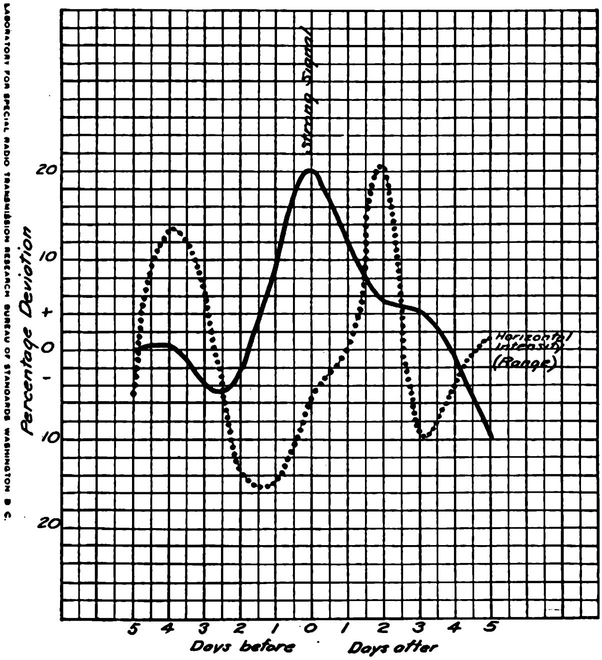

Fig. 6—Average daily deviation from the monthly mean of daylight field strength of signal (New Brunswick, WII) and of horizontal intensity (range) of the earth's magnetic field, January to July, 1927.

signals tends to be as follows:

(1) *Over Long Distances (4000-7100 km).*

The intensity of signal falls below normal for several days before the maximum magnetic disturbance which is followed by a definite increase in strength from one to four days after the storm.

(2) *Over Moderate Distances (250-400 km).*

There is an increase in signal strength above the average from two to four days before the disturbance with values below normal during the height of the storm followed by a strong increase in intensity from two to four days after the storm.

This work was done under the direction of L. W. Austin at the Laboratory for Special Radio Transmission Research, Bureau of Standards. The observations were made by E. B. Judson at that laboratory.

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Volume 17, Number 7 *July, 1929*

SOME MEASUREMENTS ON THE DIRECTIONAL DISTRIBUTION OF STATIC*

By
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Summary—*The utility of directional data on static is shown, and two types of apparatus devised for such a directional investigation are compared. It is shown that a method which gives the direction of individual crashes is superior to integrating methods. The distribution of thunderstorms over the world is discussed, and comparisons are drawn between this distribution and the observed directional distribution of static. Probable geographical locations are assigned to the sources, based upon thunderstorm data and directional observations.*

THE object of this study was primarily to determine the directional distribution of the sources of static observed at our transatlantic radio telephone receiving station located at Houlton, Maine, for the purpose of investigating the performance of the present directional receiving antennas in the reduction of static, and of furnishing basic data for the design of improved systems. It also was hoped that data might be obtained which would locate the geographical positions of these sources and thus indicate the possibility of a more favorable site for a receiving station.

Since our interest in the problem was confined to its immediate bearing upon the transoceanic radiotelephone channel, only matters of practical interest were investigated. For this reason our work was confined to the operating hours of the channel and a band of frequencies between 55 and 65 kc. We believed that local daylight observations would be the more important, not only because the greater portion of the circuit operating time is daylight, but also because night readings are subject to directional shifts and other phenomena of a more or less irregular nature.

The distribution at other frequencies probably would be modified only by non-uniform attenuation. The effect of daylight attenuates the high frequencies to a greater extent than the low frequencies, and due to the advancing shadow wall from east to west magnifies the effect of high-frequency static or signals arriving from the dark portion. Probably a wide departure in frequency from 60 kc would show a somewhat modified distribution for this reason.

* Dewey decimal classification: R114. Original manuscript received by the Institute, March 26, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

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At the outset of our investigation the ideal apparatus for our purpose seemed to be a recorder which would draw a continuous graph of the strength and direction of static. Accordingly we built an apparatus consisting of a recorder with a scale range of 40 db, an adjustible gain radio receiver, a combination of loop and vertical antenna to produce a revolving cardioidal reception diagram, and the necessary calibrating and auxiliary apparatus. The loop was turned by a motor at a rate of one revolution per fifteen minutes, and when passing through north, a contact operated a comparison oscillator for one minute. By this means the north was indicated on the record, and at

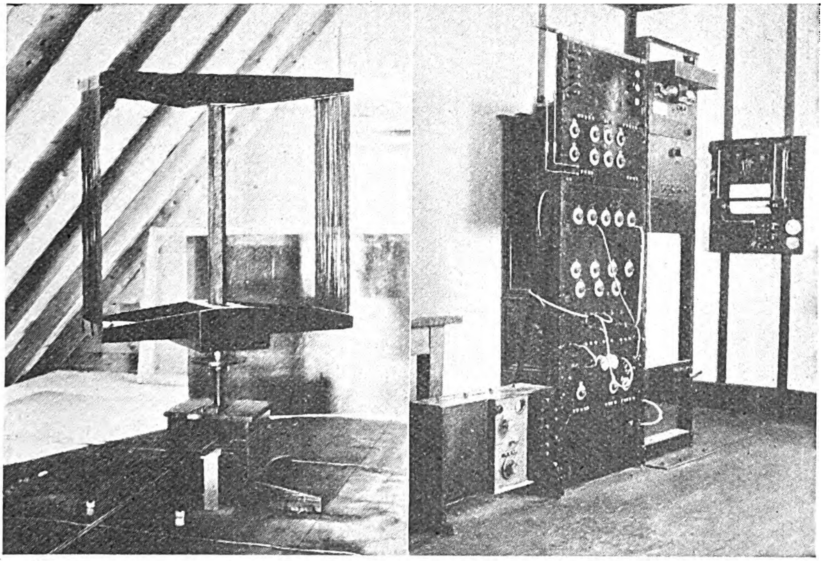

Fig. 1—Recording Direction-Finding Apparatus at Houlton, Maine.

the same time the sensitivity of the apparatus was checked. The record, by interpolation between the north marks, showed the angular relation between the minimum of the revolving cardioid and the true north.

Tests were made on distant transmitters of known location, and it was found that the apparatus traced a satisfactory curve, indicating the direction to a nice degree of precision. When applied to static, however, the device was not satisfactory, because two or more sources gave a diagram requiring mathematical analysis with many asssumptions. The time required for such an analysis was longer than that required to take the records, and the results were open to question

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on account of the necessary assumptions. Multiple sources were present during a very large percentage of the time.

When we discovered that trouble would be experienced with the recorder we cast about for some other tool for the purpose. An apparatus devised in England by Mr. Watson Watt[1] offered possibilities and this apparatus with certain modifications was used. In its original form it consisted of two crossed loops, one receptive in a N-S plane, while the other received best in an E-W plane. These loops were connected to two receivers of equal gain, whose outputs were in

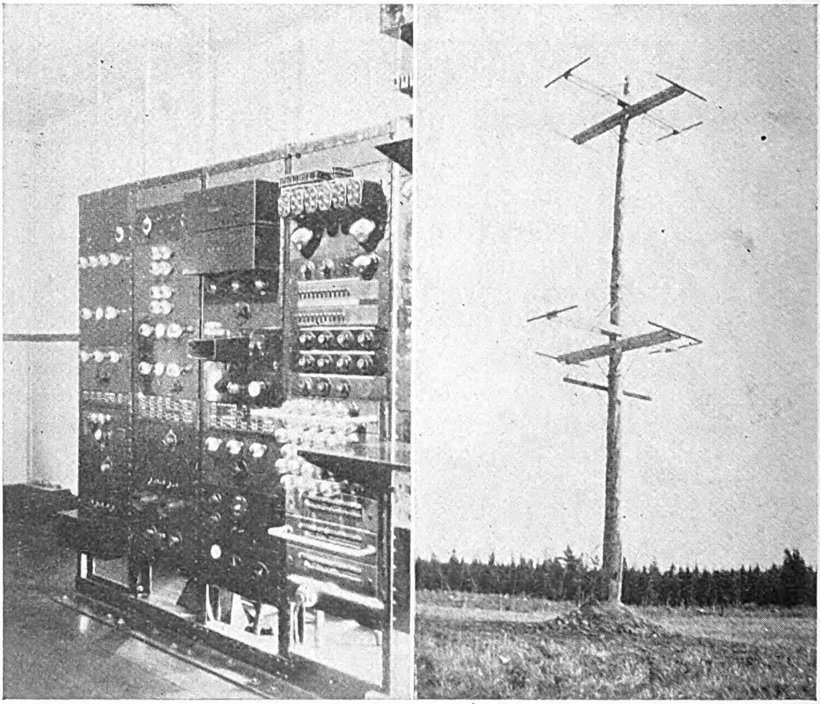

Fig. 2—Visual Direction-Finding Apparatus at Houlton, Maine.

turn connected to the vertical and horizontal deflecting elements of a low-voltage cathode-ray oscillograph tube. The potentials induced in the N-S and E-W loops, respectively, are proportional to the components of the arriving wave in these planes and after passing through their associated amplifiers produce vertical and horizontal deflecting forces on the beam. The composition of these forces causes the beam to oscillate in a plane corresponding to the angle of the arriving signal.

[1] R. A. Watson Watt and J. F. Herd, "An Instantaneous Direct Reading Goniometer," *Jour.* I.E.E., **64**, No. 353, p. 611.

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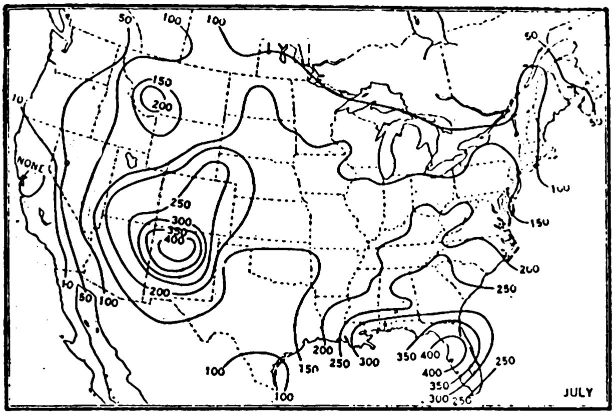
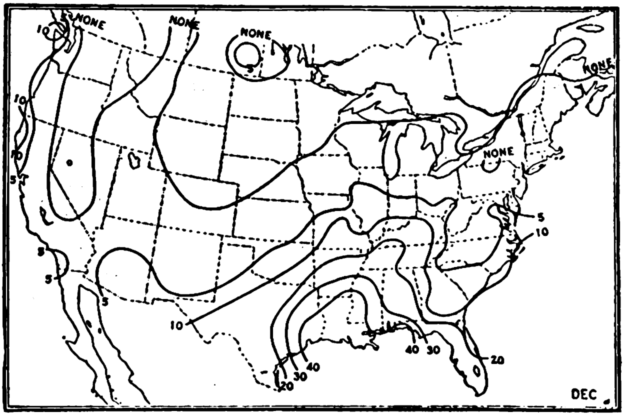


Isoceraunics, July, based upon total number of thunderstorm days, 20 years. 1904-1923



Isoceraunics, December, based upon total number of thunderstorm days, 20 years, 1904-1923

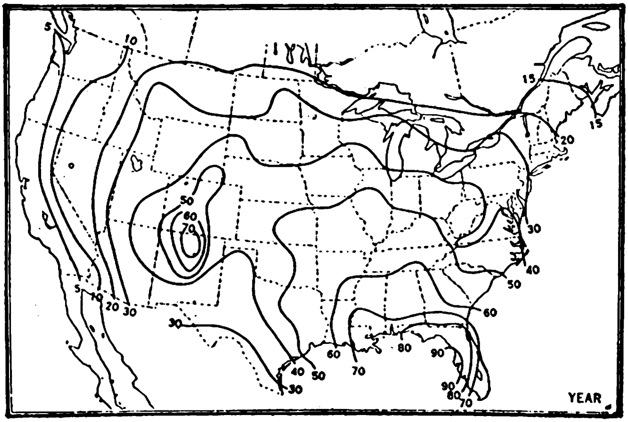


Fig. 4—Average Distribution of Thunderstorms in the United States. (Reproduced from U.S.W.B. Monthly Weather Review, 52, 337–343; July, 1925, paper by William H. Alexander).

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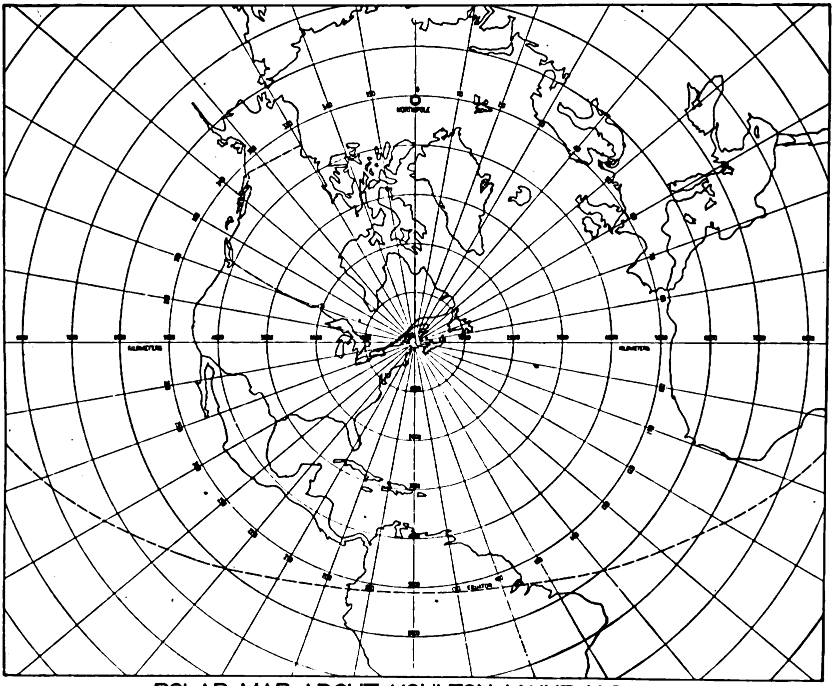
The screen of the tube is marked off with points of the compass and 10-deg. graduations, in a clockwise direction so that a crash of static would make the beam in the tube vibrate in a plane whose intersection with the screen produced a fluorescent trace, the direction of which indicated the azimuth of arrival of the disturbance. This apparatus therefore can give the direction but not the sense of the incident wave. Information obtained regarding the location of thunderstorms, etc., and records taken on the recording apparatus served to help us decide which end of the line was the index.



POLAR MAP ABOUT HOULTON MAINE, U.S.A.

Fig. 5—Polar Map about Houlton, Maine.

This apparatus seeemed very satisfactory in its operation so modifications were made to make it unidirectional and to increase its ease of operation. In its final form it is shown in Fig. 2.

The method of taking observations by means of the cathode-ray tube is as follows. Each crash or grinder of static produces a momentary fluorescent line on the screen of the tube, pointing in the direction of arrival. It occurred to us that photographic recording might be of assistance, but a trial gave us unsatisfactory results, so a method of

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visual observation had to be used. Two men are required, one to note the readings made by the other. At the beginning of the observation the apparatus is adjusted to give a nearly full scale deflection on the static. The sensitivity of the apparatus in microvolts per meter per centimeter of deflection is then measured and noted on the form. The observer, after a minute in which his eyes become accustomed to the light, begins a 5-minute run timed by his assistant. At each crash of

DR-119

CATHODE RAY DIRECTION FINDER NOISE OBSERVATION
AMERICAN TELEPHONE AND TELEGRAPH CO.

FREQUENCY 56 KC MEASURED AT Houlton Me DATE Dec 3 1928 TIME 14:15 GMT DURATION 5 Mins

ANTENNA IMPROVEMENT DATA : NOISE ON LOOP ______ µV/M
6-A NOISE ON ______ ANT. ______ TU, IMPROVEMENT ______ TU.
6-A NOISE ON St. Bo. ANT. −8 TU, IMPROVEMENT 15 TU.
6-A NOISE ON ______ ANT. ______ TU, IMPROVEMENT ______ TU.

C.R.D.F. SENSITIVITY DATA: BAND WIDTH 1200 ~
I.F.A. STEPS – NO. 1 10 NO. 2 11 DEM. OSC. STEP 7
METER 60 TU 29.5 µV/M 315 DEFLECTION 5 Cm
SENSITIVITY 63 µV/M PER CENTIMETER.

DEG E OF N	DEFLECTIONS IN CENTIMETERS	SUM	µV/M	DEG E OF N
0				0
10				10
20				20
30				30
40				40
50				50
60				60
70	5552	17	1071	70
80	351355335552332551 23	69	4347	80
90	2112322311323211152312313113 5342	72	4536	90
100				100
110	1	1	63	110
120	1	1	63	120
130	2112112	10	630	130
140	31121	9	567	140
150	1	1	63	150
160				160
170				170
180	213	6	378	180
190	66636133116613662652111666516665552615 5122	165	10395	190
200	111666666666551555 55552	111	6993	200
210	121	4	252	210
220	22	4	252	220
230				230
240				240
250				250
260				260
270				270
280				280
290				290
300				300
310				310
320				320
330				330
340				340
350				350

REMARKS: Temp 31°F
Bar 30.20"
Clear

70-80 Low pressure area N of N.F.
90 Africa
130-140 Unknown
190-200 Low pressure area over Bahamas
No Thunder Storms reported in U.S.

Fig. 6—Sample of Record of a Visual Observation.

static he calls off the intensity as estimated in centimeters, six being the maximum, and the direction to the nearest 10-deg. graduation on the tube. These data are recorded by the assistant on the form shown in Fig. 6. At the end of the 5-minute run the deflections observed in each 10-deg. sector are totalled and multiplied by a conversion factor to obtain the relative noise, the units of which are 1 µv per meter per 5 minutes. The conversion factor is obtained by a measurement of the output of a comparison oscillator required to give a 5-cm deflection. This oscillator output is then related to the field strength by use of the ordinary methods.

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Daily measurements are made at 9 A.M., 12 noon, and 5 P.M. EST, and the results are averaged and analyzed in the form of monthly reports. In order to prevent this paper from becoming too voluminous, we have not included our monthly averages, but have made one set of curves covering the closely related period of April to September, and since complete winter data are not available at this time, we have taken December as representative of the winter months.

The fact that static may come from great distances has been proved by means of simultaneous records made of static crashes in Hawaii, New York, and Germany.[2] We believe that for receiving in Maine the most important source of static is thunderstorms in the United States and Canada, after which we put thunderstorms in other portions of the globe. In addition to actual thunderstorms we find static accompanying weather disturbances such as electrified clouds, etc., which have not reached the point of producing audible thunder. As a working hypothesis it may be assumed that such static is produced on the southeast edge of an advancing low-pressure area, especially if precipitation occurs. This condition when accompanied by uprushing winds according to Humphreys[3] tends to produce a thunderstorm. Therefore in the absence of other data, thunderstorm charts would be the most logical index of the location of static sources. The above theory seems to be strengthened by our Houlton measurements.

According to available information on the subject of thunderstorms, they are much more frequent on land than over the oceans. The period of highest frequency is given as 2 to 4 P.M. on land in summer and about 4 A.M. over the oceans. Ocean thunderstorms are said to be more frequent in winter than summer. Basing our prediction of the distribution of static on average thunderstorm data alone, the principal disturbed areas are shown in Table I, compiled from Figs. 3 and 4. These concentrated sources have been arranged in order of their distances from Houlton, which would be expected to be a measure of their importance. The season has been designated by the representative month to avoid ambiguity of northern and southern hemisphere seasons.

The directional distribution of received atmospherics is also a function of the radio attenuation. When the transmission path is over land the static is weaker, due to land attenuation, than if it had traveled only over water. A diurnal variation must be expected

[2] M. Baumler, "Simultaneous Atmospheric Disturbances in Radio Telegraphy," Proc. I.R.E., 14, 765–771; December, 1926.
[3] Prof. William J. Humphreys, "Physics of the Air."

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because day and night attenuation differ considerably. Static arriving from the dark side of the shadow wall being attenuated to a smaller extent than that arriving from the illuminated portion of the globe produces a distortion of the distribution curve which would be expected if this phenomenon were disregarded.

Data analyzed but not given in this paper, based on circuit time lost on the transatlantic radio channel, and on monthly values of relative noise, show a fairly good connection between thunderstorm

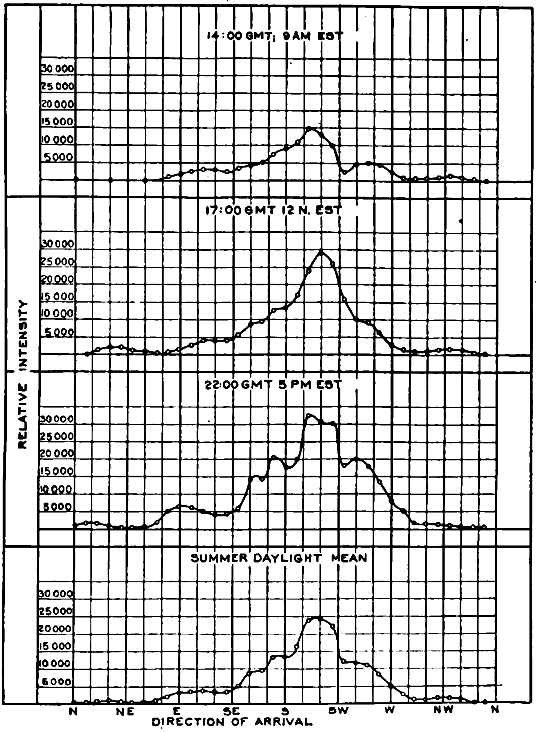

Fig. 7—Observed Directional Distribution of Static from Houlton, Maine, April–September, 1928.

frequency in the United States and these values. It is fortunate that it is only the very strong summer static that causes our circuit troubles. The weak winter variety from long distances is further reduced by directional reception and is overridden by strong signal fields, causing little lost time.

Examining the curves of Fig. 7 we note maximum noise from 210 deg. increasing as the hour becomes later. Due to the magnitude of the separate crashes observed, we have ascribed this source to Florida

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and the southern Atlantic coast states. A submaximum at 250 deg. at 1400 GMT probably is due to Mexico and disturbances in the United States in this direction. This sector shows somewhat less markedly at 1700 and 2200 GMT. At 2200 GMT a rather pronounced submaximum appears at 90-100 deg. which may be African static taking advantage of the lower attenuation due to approaching darkness from the east. A bump on the curve is also evident at this time which might be charged against the area at sea off Argentina, although

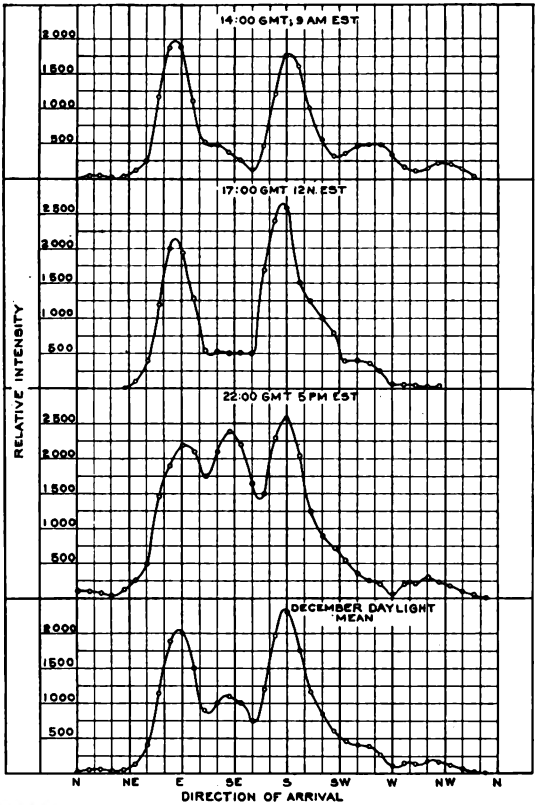

Fig. 8—Observed Directional Distribution of Static from Houlton, Maine December, 1928.

this is purely conjecture. There is a very noticeable blanketing effect due to North American static which makes all these long distance phenomena stand out less sharply than desirable.

The winter curves of Fig. 8 show a very important maximum at 90 deg. which probably is due to Africa. Another slightly higher maximum is at 180 deg. which we feel justified in ascribing to South

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America. A maximum at 130 deg. is observed at 2200 GMT which may be due to equatorial static in midatlantic.

Besides these principal maxima, we have at 1400 GMT several submaxima, for example one at 250 deg. which may be due to Texas thunderstorms. A very poorly defined maximum at about 300 deg. has not yet been explained. Static from this sector is also recorded at 2200 GMT.

Table I seems to fit the observational data astonishingly well, leaving only two points uncovered. The thunderstorm areas in Louisiana and Mexico do not distinguish themselves on our winter curves. This fact may be due to high overland attenuation and to the blanketing effects of other sources. The East Indian area, which seems extremely important on the charts, does not make its appearance at all on the curves. This may be due to the extreme length of the transmission path, or to the fact that on account of its almost antipodal position it arrives from an unexpected direction and is blanketed by stronger sources.

TABLE I

DIRECTIONS OF PRINCIPAL THUNDERSTORM AREAS FROM HOULTON, MAINE

Geographic Location	Approximate Bearing	Season
Florida	N210E	July
Mexico	N240E	"
New Mexico	N260E	"
Africa	N90E	"
At Sea off Argentina	N160E	"
Sumatra and East Indies	N5E	"
		December
Louisiana and Western Florida	N225E	"
Southern Mexico	N225E	"
Ecuador	N190E	"
Brazil	N165E	"
Central Atlantic near Equator	N115–140E	"
Africa	N90E	"
Sumatra and East Indies	N5E	"

At the start of our observations we expected to note evidence of disturbances from the neighborhood of the Icelandic semipermanent low-pressure area. However, none of our monthly curves shows any sign of trouble from this source. From this we are forced to conclude that low-pressure area in general do not necessarily have the electrical characteristics which at times accompany moving cyclonic depressions of steep gradient.

Our summer data show that July is the worst month for static at Houlton, and that this month also has the largest number of United States thunderstorms. The summer average curve indicates 200-220 deg. as the sector of maximum static with large quantities arriving at Houlton from the whole sector between 140 deg. and 270 deg. Minimum static at this season is received from the northern sector bounded by 290 deg. and 70 deg.

The author is indebted to Mr. F. H. Willis and staff at Houlton for the directional observations used in the preparation of this paper.

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THE ROUTINE MEASUREMENT OF THE OPERATING FREQUENCIES OF BROADCAST STATIONS*

By
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Summary—*The method of making "zero beat" measurements of the operating frequencies of broadcast stations in the Second Radio District is described, showing the method of comparing the received signal from a broadcasting station with a signal of known frequency, obtained from a 10-kc multivibrator controlled by a 90-kc quartz crystal. There is also given a description of the method used in reducing the measurement to a flexible routine procedure while still maintaining an accuracy well within the 500-cycle limit established by the Federal Radio Commission.*

For sixteen years the Radio Division of the Department of Commerce has concerned itself, as required by law, with the measurement of the radiated waves from all classes of commercial and amateur radio transmitters. Measurements of the operating frequencies of stations were made by means of a wavemeter at the transmitting station, which method was sufficiently accurate to insure freedom from interference between the relatively few stations operating prior to 1920. However, the rapid development of broadcasting, and a separation of ten kc between stations, soon demonstrated the futility of attempts to make a sufficiently accurate check of the operating frequencies of such stations by the use of an ordinary wavemeter at the station. Special wavemeters covering only the broadcast band, even when calibrated immediately before and after a visit to a station, were found entirely inadequate for checking frequencies within five hundred cycles.[1] It was therefore decided to make use of the so-called "zero beat" method, checking all stations at a given location where equipment better adapted for accurate measurement work could be installed and maintained under reasonably constant temperature conditions.

The office of the U. S. Supervisor of Radio at New York first made use of the zero beat method of measurement of the operating frequencies of distant radio transmitting stations early in 1923 at which time the measurements were confined principally to checks

* Dewey decimal classification: R210. Original manuscript received by the Institute, January 17, 1929. Presented before New York meeting of the Institute, April 3, 1929.

[1] Federal Radio Commission General Order No. 7, April 28, 1927.

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on the waves emitted by coastal telegraph stations working with ships. The method as used at that time consisted, briefly, in tuning in the signal to be measured on a non-oscillating receiver, resonating a local driver or oscillator with the incoming frequency as determined by a pair of telephones and then measuring the locally generated frequency by means of a Kolster Type "D" Decremeter. This method was successfully employed in reducing interference between coastal marine stations, and was employed with some success in checking broadcasting stations when broadcasting was conducted on only two wavelengths, namely 360 and 400 meters.

There are many sources of error inherent to the measurement method indicated above, and while these errors were not of great importance when there were few broadcast stations widely separated, numerous changes and refinements were necessary to adapt the "zero beat" method of measurement to the accurate checking of stations operating on channels 10 kc apart.

It is therefore the purpose of this paper to describe the method of frequency measurement which has been successfully employed at the office of the U. S. Supervisor of Radio at New York during the past year, and to show how the measurement of the operating frequencies of broadcast stations in the Second Radio District has been reduced to a practical routine procedure while maintaining an accuracy of measurement well within 500 cycles.

Outline of Method of Making Frequency Measurements

The method at present employed for the measurement of the operating frequencies of broadcast stations consists of seven distinct operations:

(1) The desired signal is tuned in on a selective, non-oscillating receiver used in conjunction with a large cone loud speaker;

(2) A local oscillator (hereinafter called the auxiliary generator) is resonated with the incoming signal by a combination aural and visual method;

(3) The frequency meter is then adjusted to resonance with the auxiliary generator and the dial reading recorded as the "station setting";

(4) The antenna is disconnected from the receiver and a signal of known frequency corresponding to the frequency assignment of the station under measurement is substituted in the receiver for the station signal picked up by the antenna;

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(5) The auxiliary generator is adjusted to resonance (zero beat) with the signal of known frequency as determined by aural and visual methods;

(6) The frequency meter is then readjusted and dial setting noted at the point which corresponds to this frequency, this reading being called the "crystal setting";

(7) From the two dial settings obtained, namely, the "station setting," the corresponding frequency of which is to be determined, and the "crystal setting" corresponding to the assigned frequency of the station, the deviation of the station from its assigned frequency may be readily determined provided the shape of the calibration curve of the frequency meter and the kilocycle equivalent of one degree of the frequency meter scale at this setting are known.

In order to obtain accurate results from the procedure indicated above, it is apparent that, first, an accurate method must be provided for obtaining zero beat or resonance between the incoming signal and the auxiliary generator, also between the standard known frequency calibration point and the auxiliary generator; second, a source of accurate known frequencies must be available which provides frequencies every 10 kc throughout the broadcast band; third, a frequency meter must be employed which will readily indicate changes in frequency of considerably less than 0.01 per cent. The manner in which these requirements are satisfied will be shown in the following paragraphs where each part of the equipment is described.

The equipment is installed in the Office of the Supervisor of Radio on the third floor of the Subtreasury Building at Wall, Nassau and Pine Streets, New York City. While this location is bounded by thirty-story office buildings on three sides and a 65,000-volt smoke precipitator on the fourth side, reception at night is satisfactory for our purposes. Ninety-five per cent of the Second District broadcast stations can be received with sufficient signal strength to be measured without difficulty.

Fig. 1 shows the arrangement of the measurement apparatus.

The Receiver

The receiver has two stages of tuned radio-frequency amplification, detector, and two stages of audio-frequency amplification storage battery operated, and is used in conjunction with a long single wire antenna on the roof. A switching device is used to short out turns on the higher frequencies so as to give greater selectivity on the higher frequencies in the broadcast band.

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The audio-frequency transformers employed in the set were selected as most suitable for the very low frequencies obtained in adjusting to zero beat. A Western Electric type 560 AW cone loudspeaker is used with the receiver.

An output coil from the 10-kc oscillator is coupled to the input of the first radio-frequency tube in the receiver so that when the an-

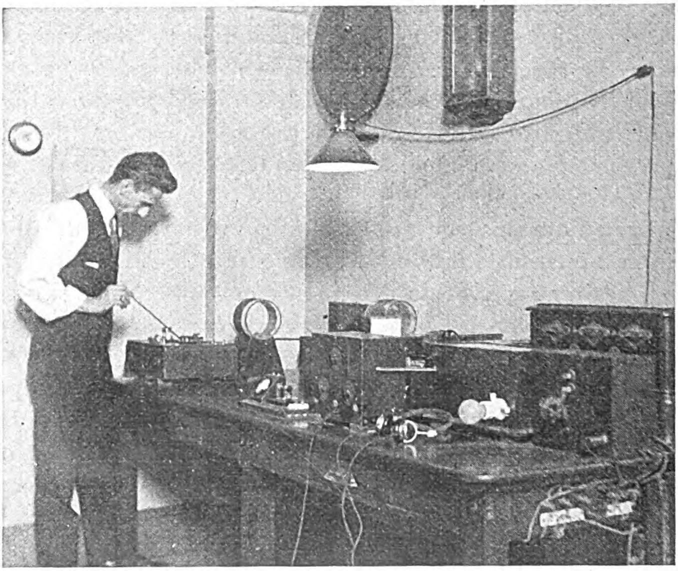

Fig. 1—View of Measurement Apparatus Employed for Checking the Operating Frequency of Broadcast Stations.

tenna is disconnected from the receiver the station signal may be replaced by the standard signal of known frequency. The receiver is shown at the extreme right of Fig. 1.

The Visual Beat Indicator

The plate circuit of the detector tube of the receiver is coupled by means of an air core auto transformer to the visual beat indicator, which consists of an ammeter having a full scale reading of one milliampere, in series with an adjustable crystal detector and switch connected across the winding of the auto transformer. The visual beat indicator and coupling coil are shown at the right of Fig. 2, and also Fig. 3.

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The Auxiliary Generator

The auxiliary generator used is the type O designed by the Bureau of Standards and operates with a UX201A tube as an oscillator in a conventional circuit. Plate current is supplied by a 100-volt storage battery and the filament is heated by a six-volt storage battery. Plug-in coils are provided for quick changes in frequency range. A slow motion dial and a long bakelite rod permit accurate adjustment of the oscillator frequency without disturbing capacity effects. Sufficient energy is developed at all frequencies in the broadcast band employing a UX201A tube as oscillator to actuate the frequency

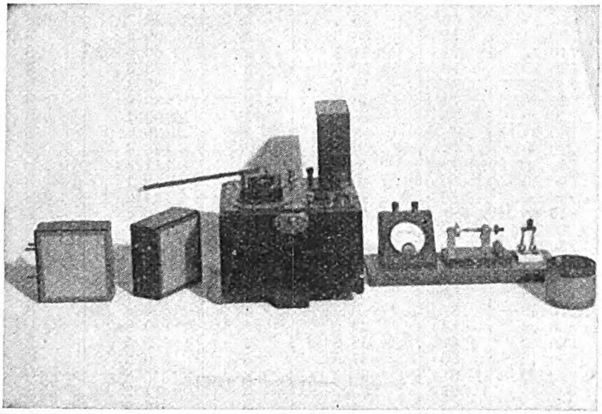

Fig. 2—Auxiliary Generator with Plug-In Coils; Visual Beat Indicator.

meter with a coupling of more than three feet, and sufficient energy at all broadcast frequencies is obtained in the receiver so that no coupling coil is necessary to feed energy from the auxiliary generator to the receiver. Each plug-in coil of the auxiliary generator has a calibration curve secured on its side which assists in identifying dial settings. The auxiliary generator and plug-in coils are shown in Fig. 2 and Fig. 7.

The 10-kc Oscillator

The 10-kc oscillator is of the multivibrator type[2] consisting of two UX201A tubes arranged in a push-pull circuit, the frequency of which is determined by the resistances and capacities used. In order

[2] J. K. Clapp, "Universal Frequency Standardization from a Single Frequency Standard," *Jour.* Opt. Soc. Amer. and Rev. Scien. Instr., 15, 33; July 1927.

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TABLE I

Calibration of Frequency Meter with 90 μh Coil

Frequency of Channel	10-kc Oscillator Harmonic	No.	Oscillator Settings	Oscillator Coil	Frequency Meter Setting	Frequency Meter Condenser Position	kc per Degree
550	550.24	55	106.0	3	121.7	A	1.10
560	560.25	56	100.0	3	130.7	A	1.12
570	570.25	57	96.5	3	139.3	A	1.10
580	580.26	58	93.0	3	147.9	A	1.17
590	590.26	59	90.0	3	156.4	A	1.12
600	600.27	60	87.0	3	164.8	A	1.23
610	610.27	61	84.0	3	172.7	A	1.26
620	620.28	62	81.5	3	0.7	B	1.27
630	630.28	63	79.0	3	8.4	B	1.29
640	640.28	64	76.5	3	16.2	B	1.31
650	650.29	65	74.0	3	23.7	B	1.34
660	660.29	66	71.5	3	31.1	B	1.36
670	670.30	67	69.5	3	38.4	B	1.39
680	680.30	68	67.0	3	45.5	B	1.40
690	690.31	69	65.0	3	52.7	B	1.42
700	700.31	70	63.0	3	59.6	B	1.44
710	710.32	71	61.5	3	66.6	B	1.46
720	720.32	72	59.5	3	73.3	B	1.48
730	730.32	73	58.0	3	80.1	B	1.50
740	740.33	74	56.5	3	86.6	B	1.54
750	750.33	75	55.0	3	93.1	B	1.56
760	760.34	76	53.5	3	99.4	B	1.59
770	770.34	77	52.0	3	105.7	B	1.61
780	780.35	78	50.5	3	111.8	B	1.61
790	790.35	79	49.0	3	118.1	B	1.61
800	800.36	80	48.0	3	124.2	B	1.65
810	810.36	81	46.5	3	130.2	B	1.67
820	820.36	82	45.5	3	136.2	B	1.71
830	830.37	83	44.0	3	141.9	B	1.77
840	840.37	84	43.0	3	147.5	B	1.72
850	850.38	85	42.0	3	153.5	B	1.72
860	860.38	86	41.0	3	159.1	B	1.80
870	870.39	87	40.0	3	164.6	B	1.85
880	880.39	88	39.0	3	169.9	B	1.83
890	890.40	89	38.0	3	175.5	B	1.83
900	900.40	90	37.0	3	0.8	C	1.94
910	910.40	91	36.5	3	5.8	C	1.92
920	920.41	92	35.5	3	11.2	C	1.92
930	930.41	93	34.5	3	16.2	C	1.98
940	940.42	94	34.0	3	21.3	C	1.96
950	950.42	95	33.0	3	26.4	C	2.00
960	960.43	96	32.5	3	31.3	C	2.02
970	970.43	97	31.7	3	36.3	C	2.04
980	980.44	98	31.0	3	41.1	C	2.08
990	990.44	99	30.0	3	45.9	C	2.11
1000	1000.44	100	29.5	3	50.5	C	2.11
1010	1010.45	101	29.0	3	55.4	C	2.11
1020	1020.45	102	28.5	3	60.0	C	2.15
1030	1030.46	103	27.5	3	64.7	C	2.11
1040	1040.46	104	27.2	3	69.5	C	2.16
1050	1050.47	105	26.5	3	73.95	C	2.17
1060	1060.47	106	26.2	3	78.7	C	2.16
1070	1070.48	107	25.7	3	83.2	C	2.22
1080	1080.48	108	25.	3	87.7	C	2.20

to maintain the frequency of the multivibrator exactly, the output of a 90-kc piezo-crystal oscillator is coupled to the multivibrator, as indicated in Fig. 3, so that the 90-kc crystal controls the ninth harmonic of the multivibrator, thus maintaining the fundamental of the multivibrator at exactly 10 kc. This is very easily accomplished since the multivibrator is fundamentally a very unstable oscillator and will respond readily to crystal control. Once adjusted, no further adjustment of the multivibrator is necessary. The multivibrator

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circuit is very rich in harmonics and from the 10-kc fundamental we have readily identified all harmonics lying within the broadcast band, that is, from the 55th to the 150th.

The frequency of the ninth harmonic of the mulivibrator is known with the same accuracy as the frequency of the 90-kc crystal, which in this case is better than one part in 10,000 (Bureau of Standards calibration) at a temperature of 29.2 deg. C. A thermostat is employed to maintain the temperature of the crystal within two-tenths of one degree of 29.2 deg. C thus reducing the change in frequency due to temperature variations to a negligible quantity.

The circuit in which the 90-kc crystal oscillates is a Bureau of Standards type piezo-crystal oscillator employing a UX201A tube utilizing 80 volts of storage battery for plate supply and a 6-volt

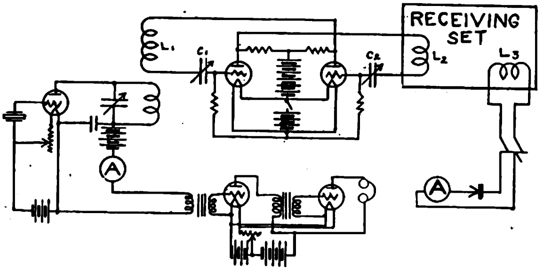

Fig. 3—Circuit Diagram of Crystal-Controlled 10-kc Oscillator.

storage battery for filament heating. A two-step audio-frequency amplifier is coupled in the plate circuit of the piezo-crystal oscillator for observing and checking the adjustment of the multivibrator.

The adjustment of the 10-kc oscillator is checked by noting the number of intermediate points at which beats are heard with the multivibrator in operation, lying between two successive beats from the crystal oscillator alone, beating with the auxiliary generator, which are separated by the fundamental frequency of the crystal oscillator, in this case 90 kc. For example, beats are obtained between the 90-kc crystal oscillator and the auxiliary generator with the auxiliary generator set at 540 kc and at 630 kc. If the multivibrator is now placed in operation and eight intermediate beat notes are obtained between 540 kc and 630 kc with the ninth point coinciding with the crystal point, it is then apparent that the 90-kc interval between 540 kc and 630 kc has been divided into nine equal parts, hence the beats are ten kc apart and must originate from a 10-kc funda-

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mental. If there are nine intermediates from the multivibrator, then the fundamental frequency is 90/10, or 9 kc. Fractional harmonics are disregarded throughout. J. K. Clapp describes in detail the method of checking the adjustment of the multivibrator in the paper to which we have already referred.

In actual practice, the 90-kc crystal-controlled 10-kc oscillator functions in a manner similar to that of a crystal oscillator provided with a crystal ground for 10 kc. The method is superior to utilizing the fractional harmonics of the 90-kc crystal oscillator directly, as these fractional harmonics vary greatly in strength and are not spaced 10 kc apart. The multivibrator could be controlled at 10 kc by means

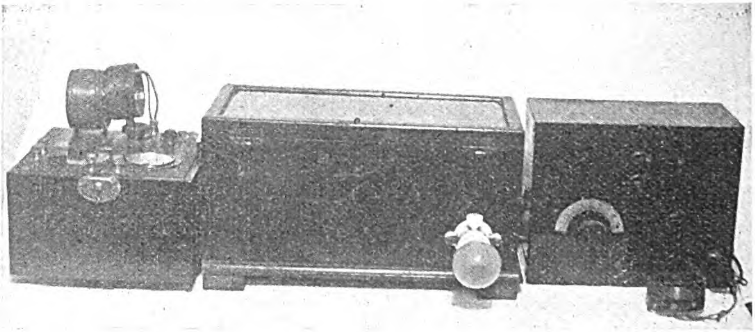

Fig. 4—90-kc Crystal Oscillator with Temperature Control Crystal Chamber and 10-kc Oscillator.

of other crystals which are exact multiples of ten merely controlling a different harmonic of the multivibrator; for example, a 150-kc crystal can be made to control the 15th harmonic of the 10-kc oscillator. A device of this kind might be of use in the calibration of broadcast receivers for the various channels. Fig. 4 shows the 10-kc oscillator at the right, and next to it the heat controlled chamber for the piezo crystal which operates in the oscillator at the left. The coupling coil of the 10-kc oscillator is seen at the left coupled closely to the coil of the crystal oscillator, and the output coil which feeds harmonics to the receiver is in front of the 10-kc oscillator at the right.

The Frequency Meter

The frequency meter consists of two coils, of 90 μh and 30 μh inductance, respectively, either of which may be connected across the variable condenser which has a maximum capacity of 1000 $\mu\mu$f.

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The coils are wound with litzendraht wire (composed of 96 strands of No. 38 wire) spaced on 6-in. Pyrex forms with a diameter to length ratio of 2 to 1, which is nearly the ideal ratio for maximum inductance with a given length of wire. The wire is secured to the form with pure varnish applied to the under side of the wire while winding. Coils wound in this manner do not loosen as a result of temperature changes. With coils of this type as shown by E. L. Hall of the Bureau of Standards, it is possible to detect a change of 30 cycles at a frequency of 1000 kc.[3] The resonance indicator consists of a microammeter in series with a crystal detector coupled to the condenser by means of a coil and an aluminum plate.[4] A combination of capacity and inductive coupling is employed to give uniform response over the frequency range of the meter. The microammeter has a maximum scale reading of 200 microamperes and will show full scale deflection when the frequency meter is coupled to the coil in the auxiliary generator at a distance of three feet. A six to one geared vernier dial expands the condenser scale and reduces the kilocycles per degree to permit accurate reading of the dial settings. The resonance peaks on the frequency meter are so pronounced that settings may be duplicated to 0.05 of one degree on the condenser vernier dial. The frequency meter is shielded and grounded and adjusted by means of a long bakelite rod to eliminate entirely the effect of body capacity. We have found that the microammeter connected to the frequency meter, as shown in Fig. 6, produces much sharper resonance indications than can be obtained with a milliammeter connected in the grid circuit of the auxiliary generator (the latter method of indicacating resonance commonly known as the "grid dip" method).

As a result of the loose coupling enployed, the change in frequency produced in the auxiliary generator when the frequency meter is brought into resonance is less than one cycle per second at the lower frequencies in the broadcast band, and at the higher frequencies does not exceed five cycles per second. With such small frequency change, it is impracticable to employ the method[5,6] of noting the point of zero reaction between the two detuning points when the frequency meter is resonated with the auxiliary generator, since the latter

[3] E. L. Hall, Technological Papers of the Bureau of Standards, No. 330, page 118.

[4] M. S. Strock, Scientific Papers of the Bureau of Standards, No. 502, page 116.

[5] C. B. Aiken, "A Precision Method for the Measurement of High Frequencies," Proc. I.R.E., **16**, 126; February, 1928.

[6] August Hund, "Uses and Possibilities of Piezo-electric Oscillators," Proc. I.R.E., **14**, 461 (footnote); August, 1926.

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method of indicating resonance is inoperative without considerable reaction between the two circuits. Fig. 5 shows the frequency meter, and Table I lists the approximate settings of the frequency meter for the broadcasting frequencies between 550 and 1100 kc. The last column of Table I indicates the kilocycles per degree on the condenser dial of the frequency meter for each broadcast channel.

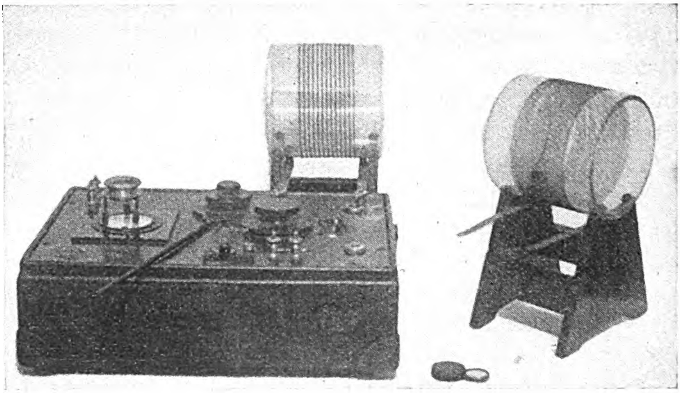

Fig. 5—Frequency Meter.

Fig. 6 shows the circuit used in the frequency meter, while Fig. 8 indicates the shape of the calibration curve of the frequency meter. Fig. 9 shows resonance curves of the frequency meter using the 30-μh and 90-μh coils, respectively.

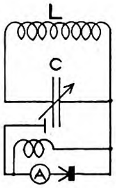

Fig. 6—Circuit Diagram of Frequency Meter.

Practical Operation and Results Obtained

In the outline of method given above, we have indicated the procedure followed in making a measurement of the operating frequency of a broadcast station. It will be noted from a study of Table I that the kilocycles per degree on the frequency meter condenser scale range from 2.20 kc per degree at 1080 kc to 1.10 kc per degree at

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550 kc, which indicates that the calibration curve of frequency plotted against condenser degrees is not quite a straight line for the type of condenser used. However, unless the frequency of the station under measurement is actually one or more kc removed from the assigned frequency, the "station setting" on the frequency meter will differ from the "crystal setting" by a matter of only a few tenths of one degree of the condenser scale. For this extremely small portion of its length, the calibration curve of the frequency meter may be assumed to be a straight line, and in fact, since the "station setting" can never be more than 5 kc from some "crystal point" (the 10-kc oscillator furnishes harmonics at 10-kc intervals), the error introduced by assuming the curve to be a straight line, does not, under any condition of use, reach a value as great as 25 cycles. The possible

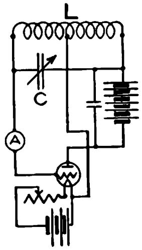

Fig. 7—Circuit Diagram of Auxiliary Generator.

error from this source is reduced as the "station setting" approaches the "crystal setting".

Curve I of Fig. 8 shows the portion of the calibration curve for the 90-μh coil of the frequency meter between 690 kc and 830 kc, and curve II of Fig. 8 shows the portion of the calibration curve of the 30-μh coil of the frequency meter between 1300 and 1450 kc. Using the 30-μh coil of the frequency meter between 1100 and 1500 kc, it is found that the kilocycles per degree range from 2.20 kc per degree at 1100 kc to 3.13 kc per degree at 1500 kc. The kilocycles per degree, using the 30-μh coil, are therefore slightly greater on the higher frequencies than the kilocycles per degree on the 90-μh coil using the latter coil for the lower frequencies in the broadcast band.

It is therefore an advantage to measure the frequencies of the broadcasting stations in the region of 1500 kc by employing the second harmonic of the auxiliary generator, rather than the fundamental frequency. For example, a 1500-kc station could be more accurately measured by adjusting the auxiliary generator to 750 kc. The dif-

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ficulties inherent in the usual methods of obtaining zero beat adjustments have been overcome by the combination aural and visual beat method employed, which utilizes a large cone loud speaker for following the beat note down to the point where the visual beat indicator commences to function, which is in the neighborhood of 15 cycles. From this point to actual synchronism, the visual beat indicator

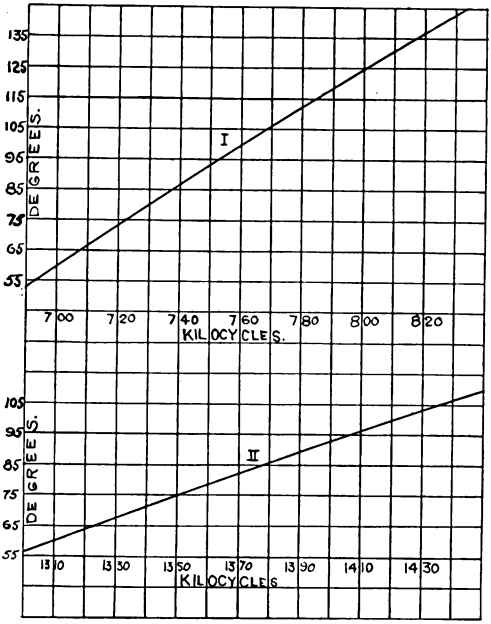

Fig. 8—Frequency Meter Calibration Curve.

produces visual indications of the beat frequency. The visual beat indicator has been successfully employed in resonating the auxiliary generator with the carrier frequencies of many of the more stable carriers of stations in the Second Radio District, and in fact, visual beats have been obtained on stations located as far distant as Denver, Colorado. In resonating the auxiliary generator with the harmonics of the 10-kc oscillator, the visual beat indicator is again utilized.

On account of interference conditions in the vicinity of the Subtreasury Building, measurements of the operating frequencies of broadcast stations are not regularly commenced until after 4:00 P.M., and from that time until approximately midnight it is customary

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TABLE II

TYPICAL LOG OF MEASUREMENTS

DEPARTMENT OF COMMERCE
Radio Division
New York City

Room Temp.
74 deg., 5 P.M.

Barometer
29.96, 5 P.M.

Weather
Clear, light
N. W. wind

Zero Beat Measurements
Thursday, September 20th, 1928.

Zone No. 1
Dist. No. 2

Station*	Time	kc Deviation	High Low	Operating Frequency	Assigned Frequency	Remarks
1	2:29 P.M.	0.1	High	610.1	610	Visual beats
2	2:33 “	0.0	—	660.0	660	Visual beats O.K.
3	3:15 “	0.3	Low	1019.7	1020	Carrier slightly unsteady
4	3:24 “	0.0	—	760.0	760	Slight swinging
5	3:58 “	Carrier too unsteady to be measured				
6	4:26 “	2.2	Low	1217.8	1220	Fluttery carrier
7	4:47 “	0.1	Low	1119.9	1120	
8	5:52 “	1.9	High	1501.9	1500	Swinging
9	5:55 “	Station not on the air as advertised in program for this date				
10	5:57 “	0.2	Low	1369.8	1370	Swinging
11	6:15 “	0.8	High	1170.8	1170	Swinging
12	6:19 “	0.5	High	860.5	860	Slight swinging
13	6:28 “	0.9	Low	809.1	810	Visual beats
14	6:32 “	0.3	High	920.3	920	Visual beats
15	6:37 “	0.2	Low	969.8	970	Heterodyne
16	6:43 “	4.9	High	1474.9	1470	
17	6:53 “	0.1	Low	1499.9	1500	Heterodyne
18	6:57 “	0.2	Low	1119.8	1120	Carrier swinging
19	7:03 “	0.2	High	1220.2	1220	Carrier swinging
20	7:10 “	0.8	Low	1369.2	1370	
21	7:15 “	0.2	Low	1409.8	1410	Heterodyne
22	7:19 “	0.2	High	1270.2	1270	
23	7:25 “	0.0	—	1250.0	1250	Heterodyne
24	7:30 “	0.1	High	1320.1	1320	Very bad generator hum
25	7:41 “	0.1	High	1470.1	1470	Bad QRM from CW telegraph station
26	7:47 “	0.3	High	1170.3	1170	Visual beats
27	7:52 “	0.2	High	710.2	710	Visual beats
28	8:00 “	0.0	—	660.0	660	Visual beats O.K.
29	8:03 “	0.1	High	610.1	610	Visual beats
30	8:07 “	0.0	—	570.0	570	Visual beats O.K.
31	8:17 “	0.0	—	760.0	760	Visual beats; heterodyne
32	8:22 “	0.1	Low	809.9	810	Visual beats
33	8:31 “	0.2	Low	789.8	790	Visual beats
34	8:40 “	0.4	High	1500.4	1500	Heterodyne
35	8:46 “	0.0	—	1370.0	1370	Heterodyne; fading badly
36	8:54 “	0.8	Low	1389.2	1390	Heterodyne; fading
37	9:18 “	0.5	Low	1269.5	1270	Heterodyne
38	9:31 “	0.4	Low	1019.6	1020	Heterodyne very strong Fading
39	10:18 “	0.2	Low	1119.8	1120	Two bad heterodynes; bad hum on station
40	10:27 “	0.2	Low	1319.8	1320	Bad heterodyne; fading
41	11:05 “	Station not on the air as specified in station application				

*Numbers have been substituted for the actual call letters of stations.

to log about 35 Second District stations, and from 5 to 20 stations outside the district, depending upon prevailing receiving conditions.

The sample log sheet (Table II) for September 20, 1928 is typical of measurements made three times weekly of the operating frequencies of stations in the Second Radio District. Stations found to be deviating (more than 500 cycles) are immediately notified by letter of their deviations, and subsequently checked to ascertain whether such deviations have been corrected.

A study of Table II indicates that the carriers of many stations are unstable, preventing accurate zero beat adjustment, and there-

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fore the frequencies cannot be accurately determined. In other cases it will be noted from the "Remarks" column that visual beats have been obtained on both the carrier wave of the station and the harmonic from which the frequency of that particular station was determined. Where two or more stations are operating simultaneously on nearly the same frequency, heterodyne beat notes occur which may seriously interfere with the adjustment of the auxiliary generator to resonance with the carrier it is desired to measure. In

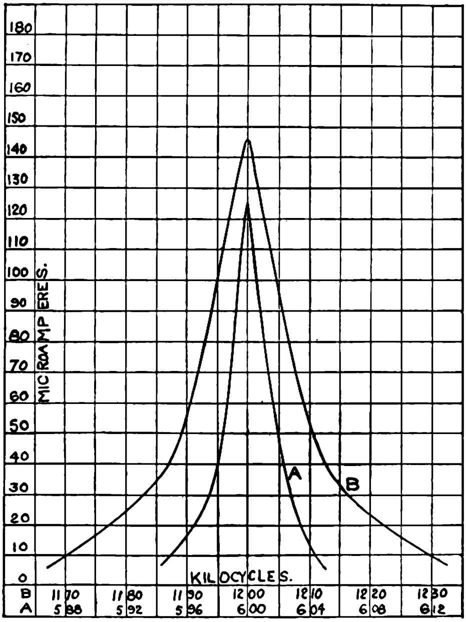

Fig. 9—Resonance Curves of Frequency Meter at 600 kc and 1200 kc.

such cases, no measurement is made unless the carrier can be identified and the desired signal separated from other stations.

It will be noted from Table I that the frequencies of the harmonics obtained from the 10-kc oscillator do not fall exactly on the channels assigned to broadcasting stations. This is due to the fact that the quartz crystal which controls the multivibrator has a fundamental frequency slightly in excess of 90 kc.

The fact that the 10-kc crystal harmonic points do not exactly coincide with the assigned frequencies does not in any way affect the procedure, nor the accuracy of the results obtained, provided the

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actual frequency of the harmonics is known with accuracy. While the system, as at present employed, uses a frequency meter to interpolate between the calibrating point and the station setting on the frequency meter, it is planned to use a calibrated audio-frequency oscillator to measure the beat note obtained when the signal to be measured is beating with the appropriate harmonic of the 10-kc oscillator.

As indicated in our early paragraphs, the problem was to devise quickly, with the apparatus then available, an accurate method of checking broadcasting stations on their assigned frequencies. The results obtained with the apparatus described have proved the method of comparison with the harmonics of a 10-kc source to be vastly superior to the previous method of measurement using a wavemeter. The results of simultaneous measurements by the use of the equipment described and several laboratories equipped to make frequency measurements with precision have indicated in most cases an agreement within 100 cycles.

In closing this paper, the authors wish to express their appreciation of the assistance rendered by the Radio Division of the Bureau of Standards, and particularly to E. L. Hall of that organization, who made several calibrations of the piezo-crystal oscillator used in connection with the apparatus described.

Additional References

Frederick W. Grover, "Formula and Tables for the Calculation and Design of Single Layer Coils," Proc. I.R.E., **12**, 193; April, 1924.

August Hund, "A Method of Measuring Radio Frequencies by Means of a Harmonic Generator," Proc. I.R.E., **13**, 207; April, 1925.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

EAST-WEST AND NORTH-SOUTH ATTENUATIONS OF LONG RADIO WAVES ON THE PACIFIC*

BY
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Summary—*A comparative study of low-frequency signals of high power stations in the Pacific area has been made, with particular reference to relative attenuation in north and south directions as compared with attenuations in east and west directions. A comparison of observed field strengths in microvolts per meter with the results calculated by various proposed formulas has been made. While the agreement is none too good with any of the formulas, the results indicate that east and west attenuation is decidedly greater than north and south during the daylight hours in the fairly high latitudes. They also indicate that in comparing observed results with different transmission formulas due account must be taken of the type of experiments upon which the formulas in question were based. It is suggested that by the inclusion of terms in the formulas, depending upon both direction and latitude, it might be possible to construct or modify some of the existing formulas to fit the general case.*

IT has been theoretically shown by Nagaoka,[1] Pickard,[2] Appleton,[3] and Nichols and Schelleng,[4] that the east-west attenuation of radio waves ought to be greater than the north-south attenuation. Nagaoka and Pickard dealt with the problem by discussing the ionized state in the upper atmosphere, whereas Appleton, and Nichols and Schelleng attributed it to the effect of the terrestrial magnetism. However, as very little quantitative experimental information has been heretofore given to verify the above-mentioned theories, the results recently obtained by the authors will be given in the present paper.

Throughout the entire year of 1927, the measurements were made at a station near Tokyo at certain specified times of a day on the field intensities of radio signals received from several long-distance, long-

* Dewey decimal classification: R113. Original manuscript received by the Institute, March 2, 1929.

[1] H. Nagaoka, "On the propagation of electric waves on the earth's surface and the ionized layer of the atmosphere," *Proc.* Tokyo Math. Phys. Soc., p. 403, 1914.

[2] G. W. Pickard, "Static elimination by directional reception," PROC. I. R. E., **8**, 358; October, 1920.

[3] E. V. Appleton, "Geophysical influences on the transmission of wireless waves." The Phys. Soc. of London, and Royal Meteorological Society, a discussion on "Ionization in the atmosphere and its influence on the propagation of wireless signals." 16D, Nov. 28, 1924.

[4] H. W. Nichols and J. C. Schelleng, "Propagation of electric waves over the earth," *Bell Sys. Tech. Jour.* **4**, 215, 1925.

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wave, high power stations. The method of measurement and results obtained by it were already published.[5] Among the observed stations were included Bolinas, Kahuku, Malabar, Palao and Saigon, which are compared in this paper.

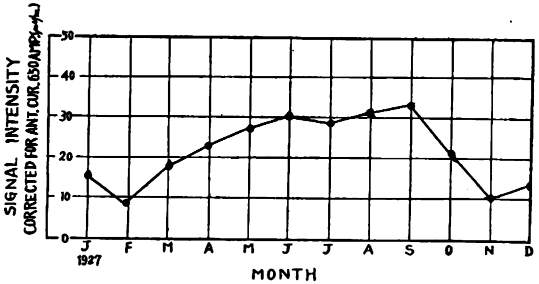

Fig. 1—Monthly Average Variations of Field Intensities, Bolinas.

As shown in Table I, Bolinas and Kahuku are situated nearly to the east, and Palao nearly to the south, while Malabar and Saigon are located almost to the southwest of the receiving station.

TABLE I

Observed Station	Direction* (deg)	Great Circle Distance (km)	Percentage of the Sea on the Path.
Bolinas	89° 7′	8,145	100
Kahuku	103 43	6,095	100
Malabar	217 46	5,920	75
Palao	191 13	3,280	96
Saigon	233 39	4,340	90

* Measured clockwise from the true north.

According to the theory advanced by Nichols[6], the greater attenuation of waves in the direction of east and west is due to that of a component of electric vector of the waves parallel to the terrestrial magnetic field, the waves being considered as composed of electric vectors parallel and perpendicular to the earth's magnetic field. The amount of the east and west attenuation thus depends on the inclination of the earth's magnetic field in a particular locality considered; that is, at a place where the magnetic inclination is small, the attenuation will not be great even in the direction of east and west. Therefore, there will be no appreciable difference between the attenuation in the direction of east and west and that of north and south. From

[5] T. Nakai, "Long distance radio receiving measurements." Researches of the Electrotech. Lab., No. 217, 1927. E. Yokoyama and T. Nakai: "The measurements of the field intensities of some high-power long-distance radio stations." Researches of the Electrotech. Lab., No. 229, June, 1928; No. 233, July, 1928; No. 238, Sept., 1928.

[6] Same reference as in 4.

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the above reasoning, it follows that the southwest propagation either from Malabar or Saigon where the magnetic inclination is small, can be considered to be of the nature of north and south propagation as that from Palao.

As shown in Table I, the great circles passing through the receiving point and the observed stations do not cross a large extent of land

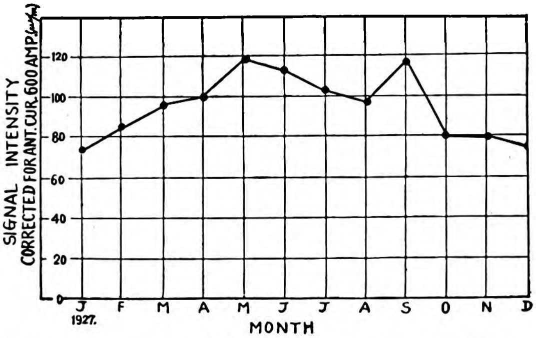

Fig. 2—Monthly Average Variations of Field Intensities, Kahuku.

which is apt to complicate the attenuation of waves, but lie almost entirely over the sea. Under such relative positions of stations, the transmission in the direction of east and west may be satisfactorily compared with that in the direction of north and south.

In Table II are given the wavelengths, radiation heights of antennas and antenna currents of the stations as well as times of measurements which were all chosen so that both transmitting and receiving stations are in daylight.

TABLE II

Observed Station	Wave-length (m)	Rad. Height of Antenna (m)	Ant. Current (a)	Time of Measurement GMT	LTTS	JCST
Bolinas	13,100	51	650	2240	2.40 P.M.	7.40 A.M.
Kahuku	16,975	80	600	0300	4.30 P.M.	0.00 P.M.
Malabar	15,600	380	A 500 M 350	0100	8.00 A.M.	10.00 A.M.
Palao	10,000	65	120	0220	11.20 A.M.	11.20 A.M.
Saigon A	16,050	145	420	2330	6.30 A.M.	8.30 A.M.
Saigon B	20,800	145	600	0540	0.40 P.M.	2.40 P.M.

A........................Arc
M.......................Machine
LTTS....................Local times of transmitting stations
JCST....................Japanese Central Standard Time

Monthly averages (5 to 9 points for each month) of the field intensities for the stations are plotted in Fig. 1 to Fig. 6, and their annual averages are given in column (I) of Table III. These data are roughly corrected to the day-time averages as shown in column (II) by using

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data of some 24-hour observations made throughout the whole year.

For comparison of the observed and calculated values, Eckersley's[7], Espenschied's[8], and Austin's[9] new transmission formulas are selected as the most suitable, on account of the similarity in wavelengths and

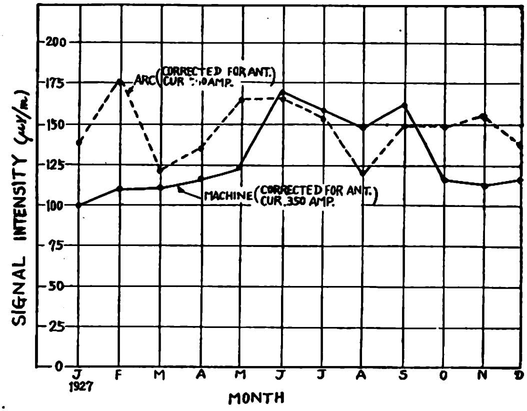

Fig. 3—Monthly Average Variations of Field Intensities, Malabar.

distances. Eckersley's is based on a series of tests which were carried out in day-time between a ship, and European and American high power stations during the voyage from England to New Zealand via Newport and Panama. On the voyage, the Pacific route was in the southwesterly direction and had little land intervening, which resembles the writers' experiments with Saigon and Malabar.

[7] $\epsilon = 377\times10^3 \dfrac{hI}{\lambda\sqrt{Rd^\circ}\sin\theta} e^{\dfrac{-0.000955d}{\sqrt{\lambda}}}$

λ	d°
10.000	1,150
13.100	700
15.600	520
16.050	500
16.975	450
20.800	400

R = radius of earth.

[8] $\epsilon = 377\times10^3 \dfrac{hI}{\lambda d}\sqrt{\dfrac{\theta}{\sin\theta}}\, e^{\dfrac{-0.005d}{\lambda^{1.25}}}$

[9] $\epsilon = 377\times10^3 \dfrac{hI}{\lambda d}\sqrt{\dfrac{\theta}{\sin\theta}}\, e^{\dfrac{-0.0014d}{\lambda^{0.6}}}$

In the above equations, h, λ, d, d°, R are in km; I in amperes, ϵ in μv per meter; θ in radians.

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Espenschied's is based on over-sea tests, nearly in the direction of east and west, made between England and the United States, the condition of which corresponds to the writers' experiments with Bolinas and Kahuku. Austin's new formula is based on the results obtained by various experimenters, and the analysis of various conditions is, accordingly, very difficult. The values calculated by the above-mentiond three formulas are given in column (III) of Table III, and the ratios of the calculated and the corrected observed values in column (IV) of the same table. Furthermore, the values calculated by Hertz's formula[10] and their ratios are also included in the table.

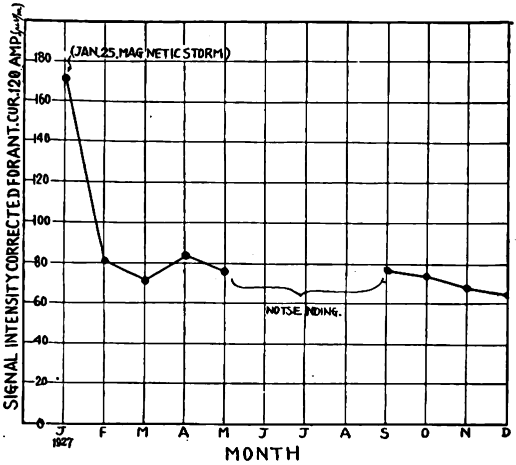

Fig. 4—Monthly Average Variations of Field Intensities, Palao.

As seen in Table III, the observed values for Bolinas and Kahuku are fairly close to those calculated by Espenschied's, whereas the values for Saigon and Palao are widely different. The calculated values for Malabar have been found by using the published figure, 380 meters, as its radiation height. The station uses the so-called "mountain antenna" and its radiation height is said to be that high. The antenna is, however, doubtful as to efficiency, at least towards Japan, because of the probable shadow effect of the mountain by which it is supported and of its poor radiation to that direction.[11] The station is, therefore, excluded from the present comparison. On the other hand, the observed values for Palao and Saigon are fairly close to those calculated by

[10] $\epsilon = 377 \times 10^3 \, hI/\lambda d$.

[11] C. W. Doetsch, "Die Grosstation Malabar-Radio auf Java," *Telefunken-Zeitung*, Nr. 40/41, S. 14, Okt., 1925.

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Eckersley whereas the values for Bolinas and Kahuku are widely different.

The coincidence in the observed and calculated values of field intensities seems thus to depend upon the direction of the transmissions on which the formula is based. This indicates that the attenuation of radio waves in fairly high latitudes is governed by the direction of their propagation. Taking this into account, it appears advisable, for

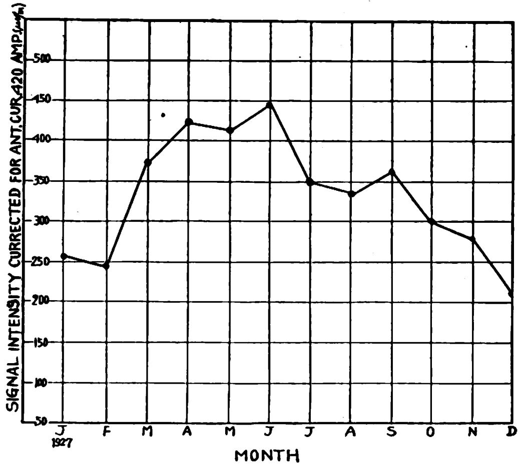

Fig. 5—Monthly Average Variations of Field Intensities, Saigon (A).

obtaining a more suitable formula, to take into consideration and introduce a factor depending on both direction and latitude.

TABLE III

Observed Station	(I) Observed Average μv/m	(II) Corrected Observed Average μv/m	(III) Calculated μv/m				(IV) Ratio of correc. obs. and calc.			
			Hertz	Eckersley	Espenschied	Austin's New	obs. Hertz	obs. Eckers.	obs. Espen.	obs. Austin N.
Bolinas	22	22	117	54	26	11	0.19	0.41	0.85	2.00
Kahuku	93	93	175	170	78	40	0.53	0.55	1.19	2.32
Malabar A	147	147	775	674	322	170	0.19	0.22	0.46	0.87
Malabar M	129	129	542	471	225	119	0.24	0.27	0.57	1.07
Palao	74	70	90	58	36	29	0.78	1.21	1.95	2.42
Saigon A	333	438	330	360	174	109	1.33	1.22	2.52	4.02
Saigon B	582	493	363	502	231	141	1.36	0.98	2.14	3.50

It is also noticeable from Table III that the observed values for Saigon and Palao are nearly twice as large as those calculated by Espenschied, and those for Bolinas and Kahuku are nearly half as small

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as the values calculated by Eckersley. This seems to indicate that north and south propagation of long waves goes on with less attenuation than east and west in rather high latitudes.

The values calculated by Austin's new formula approach all the observed values, but remain far less. As mentioned above, this is probably due to the complexity of conditions in the experiments on which the formula is based.

It is also interesting to note that the observed values in Saigon experiment exceed the values calculated by Hertz.

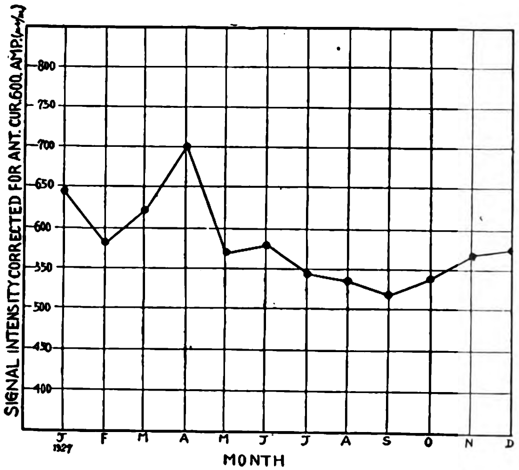

Fig. 6—Monthly Average Variations of Field Intensities, Saigon (B).

In the experiment[12] on which Eckersley's formula is based, attenuation of waves was greater at the positions of the ship between England and Newport than between Newport and New Zealand. Taking into consideration that the former course was in an east-west and the latter in a north-south or south-west direction this may be taken as an evidence of the difference in east-west and north-south wave propagations.

In addition to those, for the night transmission of radio signals at short and broadcasting wavelengths, many experimental results have also been obtained in Japan showing that signals in north and south directions are stronger than those from east or west, but it has not yet been confirmed quantitatively.

The conclusions arrived at are as follows:

[12] H. J. Round, T. L. Eckersley, K. Tremellen, and F. C. Lunnon: "Report on measurements made on signal strength at great distance during 1922 and 1923 by an expedition sent to Australia," *Jour.* I. E. E., 63, 933, No. 346, October, 1925.

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1. East-west attenuation is decidedly greater than north-south attenuation in long-wave daylight propagation in fairly high latitudes, the former being about twice as large as the latter.

2. Observed values of long-wave day-time field intensities can be estimated only by a transmission formula which is based on experiments carried out under similar conditions.

3. In order to construct a transmission formula which is universally applicable, an additional factor, depending on both direction and latitude, must be introduced.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

BOOK REVIEW

Matter, Electricity, Energy; the Principles of Modern Atomistics and Experimental Results of Atomic Investigations, by WALTER GERLACH; translated from the second German edition by Francis J. Fuchs, New York, D. Van Nostrand Company, 1928, Pp. xii+427, 119 illustrations, $6\frac{1}{4} \times 9$, cloth, $6.00.

It is much to be regretted that so few scientists on this side of the Atlantic who are doing creative work in their several fields are willing to spend the necessary time and energy for popular or semi-popular writing. In this respect both the English and Germans are leading us by at least 45°. The book before us is a good example of semi-popular science in Germany, written by a prominent contributor to contemporary advance in physics. It covers the domain of modern physics down to 1923 very thoroughly, and for that reason cannot treat any one branch of the subject in sufficient detail to meet the needs of those who are especially engaged in "atomism." Nevertheless, engineers, chemists, and other workers in allied fields will find the book a rich storehouse of information on what is doing in modern physics. Unfortunately the development of the new mechanics took place after the book was written. As a rule each chapter may be read independently of the rest.

Among the thirty chapters the following are likely to be of most interest to readers of this journal: General Atomistics, The Specific Charge of the Electron, The Magnetron, Super-Conductivity, Spectral Emissions and the Periodic System of Elements, Resonance and Dispersion, the Compton Effect, The Extension of Our Knowledge of the Electromagnetic Spectra, The Photoelectric Effect, Practical Applications of the Photoelectric Effect, Infra Red Frequencies of Chemical Radicals in Crystals, Structure Analysis by Means of X-rays, Electron-Affinity, and Radiation Measurements.

There is also a good account of the quantum theory and of the work of Gerlach and Stern on the magnetic moments of atoms.

The reader who hopes to find in the chapter on "Practical Applications of the Photoelectric Effect" an account of the use of the photoelectric cell in picture transmission, television, etc., will be disappointed, as the only applications mentioned have to do with laboratory measurements.

The task of translating has in the main been well performed, although the translator's apparent unfamiliarity with technical terms sometimes makes the book savor more of the dictionary than of the laboratory. Thus we find, in reading of the vacuum-tube amplifier for photoelectric cells, the plate current referred to as the "anode stream," and the grid as a "grating electrode."

In the last chapter on "Atomism and Macrocosmos" a brief account is given of the atomic theory as applied to the stars. The recent speculations of Eddington and Jeans are not, however, included. A few misprints occur, especially on page 318.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R113 Kruger, K. and Plendl, H. Ueber die Ausbreitung der kurzen Wellen bei kleiner Leistung im 1000 Kilometer-Bereich. (On the propagation of short waves with low power in the 1000 km range.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 85–92; March, 1929.

(Continuous communication on a frequency of 6000 kc between ground and plane over distances up to 600 km using a two-watt piezo-controlled transmitter with battery power was shown to be practical. Detailed description of experiments and explanation of results are given.)

R113.4 Kenrick, G. W. and Jen, C. K. Measurements of the height of the Kennelly-Heaviside layer. Proc. I. R. E., **17** pp. 711–733; April, 1929.

(Further contribution to the Kennelly-Heaviside layer problem is offered in the form of experimental data showing evidence of the diurnal cycles in layer height and a mathematical discussion of methods for the interpretation of group time and phase retardation experiments with the view of determining the relationship between "virtual" and "true" heights.)

R113.5 Dearlove, F. Radio frequency phenomena associated with the Aurora Borealis. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 193-195; April, 1929.

(Observations made in Labrador and Newfoundland on the effect of aurora borealis on reception at high frequencies. Two types of aurora appear; type A, a faint glow generally seen in Northern sky extending faint streaks of greenish light in all directions and appearing at a great altitude, generally moving slowly but sometimes stationary. Type B appears suddenly, consists of undulating patches of vivid greenish light. Type A and to a less extent type B, produces very abnormal types of reception for frequencies of 7500, 3750 and 1875 kc, even during daylight.)

R113.6 Lange, E. H. Note on earth reflection of ultra short radio waves. Proc. I. R. E., **17**, pp. 745–751; April, 1929.

(Computations and curves are given for the reflection coefficients and phase angles for various surface conditions in conjunction with a horizontal ultra short antenna. Theoretical polar diagrams were computed for various heights of horizontal antenna above the surface.)

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R130 Kingdon, K. H. and Mott-Smith, H. M. The operation of radio receiving tube filaments on A. C.—Part II. General Elec. *Review*, **32**, pp. 228–232; April, 1929.

(Discussion of causes of distortion resulting from use of grid-leak with a detector tube which employs a.c. on the filament. When grid becomes sufficiently positive, grid current flows causing grid voltage fluctuations which in turn give rise to a double-frequency ripple in plate current. Serious disturbances are caused if filament drop is greater than 0.1 volt.

R131 Barclay, W. A. The algebraic representation of triode valve characteristics. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 178–183; April, 1929.

(Analytical treatment of the "lumped" triode characteristic holding over the entire characteristic curve.)

R131 Decaux, B. Un abaque de classification pour les triodes de reception, application a leur choix rationnel. (A chart classifying receiving tubes.) *L'Onde Electrique*, **8**, pp. 37–40; January, 1929.

(A chart is presented in which each tube is recorded as a point, its abscissa being the logarithm of the amplification factor, and its ordinate being the logarithm of the internal resistance. The position of the point with respect to indicated zones shows for what purpose the tube is suitable.)

R133 Latour, M. A propos de la communication de M. F. Bedeau sur "Les differentes methodes de determination de la condition d'entretien des oscillations dans les emetteurs a lampes." (Re a communication from M. F. Bedeau on "The different methods of determining the condition for continuous oscillations in electron transmitting tubes.") *L'Onde Electrique*, **8**, pp. 77–79; Feb., 1929.

(A brief summary of the author's earlier analysis of the conditions for continuous operation of a self exciting three-electrode tube generator.)

R133 Mercier, J. Le mecanisme de la stabilisation des oscillations dans un oscillateur a lampes. (The mechanism for stabilizing oscillations in electron tube oscillators.) *L'Onde Electrique*, **8**, pp. 29–36, Jan.; pp. 60–67, Feb., 1929.

(A mathematical graphical study of the building up and maintenance of radio frequency in an electron tube generator. The consideration extends to various orders of magnitude of the damping constant and to the effect of a grid current.)

R133 Okabe, K. On the short wave limit of magnetron oscillations. Proc. I. R. E., **17**, pp. 652–59; April, 1929.

(The short-wave limit for radio-frequency current generator by a magnetron is theoretically considered. Experimental results in support of the theory are given. Successful production of a wavelength of 5.6 cm is reported.)

R137 Hartshorn, L. The measurement of the anode circuit impedances and mutual conductances of thermionic valves. *Proc.* Royal Soc.(London), **41**, pp. 113–125; Feb. 15, 1929.

(Application of Wheatstone bridge to measurement of plate circuit admittance or impedance and mutual conductance of an electron tube under actual conditions. Current of audio frequency was used.)

R146 Guillemin, E. A. and Rumsey, P. T. Frequency multiplication by shock excitation. Proc. I. R. E., **17**, pp. 629–651; April, 1929.

(Fundamental principles involved in theory of frequency multiplication by means of iron-core coupled circuits are briefly reviewed from standpoint of Fourier's analysis as well as that of recurring transients.)

R146 Marique, J. Note sur le calcul des etages multiplicateurs de frequence a triodes. (Note on the design of frequency multiplying stages of triodes). *L'Onde Electrique*, **8**, pp. 1–19; January, 1929.

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(Calculations are given based on the static characteristics of a tube for determining the power that can be drawn from a tube at twice or three times the frequency of the input. A simple theory is presented for choosing the best tube inductance, capacity, and grid and plate voltages for a frequency multiplying stage.)

R200. RADIO MEASUREMENTS AND STANDARDIZATION

R201.2 Lloyd, H. Note on an application of the Whiddington ultra-micrometer. *Jnl. Scientific Instruments* (London), **6**, pp. 81–84; March, 1929.

(Methods are given which have been employed for overcoming some difficulties met with in using a heterodyne micrometer and improved arrangements are described for the indication of the zero beat condition audibly or visibly.)

R210 Pession, G. and Gorio, T. Measurement of the frequencies of distant transmitting stations. PROC. I. R. E., **17**, pp. 734–744; April, 1929.

(Equipment installed in the Italian Royal Experimental Institute of Communications for radio-frequency measurements is described.)

R220 Cagniard, L. Deux examples de montages qui font intervenir la variation des caracterictiques d'un appareil recepteur ou de mesure. (Two examples of networks making use of the variation in characteristics of a receiving or a measuring apparatus.) *L'Onde Electrique* **8**, pp. 68–76; Feb., 1929.

(A circuit with its analysis is presented for the accurate measurement of capacities, self-inductances, etc. at higher frequencies. The circuit is a Wheatstone bridge employing in its resonant measuring diagonal a quadrant electrometer. The capacity of the latter being a function of its deflection increases the sensitivity of the circuit enormously.)

R230 Hartshorn, L. The measurement of the inductance and effective resistance of iron cored coils carrying both direct and alternating current. *Jnl. Scientific Instruments* (London), **6**, pp. 113–115; April, 1929.

(Method is described for measurement of effective inductance and resistance of coils of large self inductance which are required to carry a comparatively large direct current with a superposed a-c ripple. Hay's inductance bridge is used with special arrangement for independent control and measurement of the a-c and d-c components, the avoidance of earth capacity effects without grounding the a-c supply and elimination of the d-c from the vibration galvanometer used as detector without losing sensitivity. Typical results are given.)

R240 Sutton, G. W. A method for the determination of the equivalent resistance of air condensers at high frequencies. *Proc.* Royal Soc. (London), **41**, pp. 126–134; Feb. 15, 1929.

(Losses in air condensers are due to leakage through the solid dielectric and to terminal and plate resistance. A method is developed for measuring each under conditions such that the other is negligibly small. Limits of the errors to which the methods are liable are discussed and some results of practical measurements are quoted.)

R275 Jolliffe, C. B. The use of the electron tube peak voltmeter for the measurement of modulation. PROC. I. R. E., **17**, pp. 660–663; April, 1929.

(Method described whereby the peak value of the radio-frequency current is measured without modulation. The modulation is then applied and the peak value again measured.)

R300. RADIO APPARATUS AND EQUIPMENT

R329 Eckersley, P. P. and T. L., and Kirke, H. L. The design of transmitting aerials for broadcasting stations. *Jnl.* I. E. E. (London), **67**, pp. 507–526; April, 1929.

(Presents theory of the antenna as a radiator with special reference to its ability to radiate rays parallel to the surface of the earth. Account of experiments with different types of antennas designed to achieve this result is given. Theory of attenuation of waves having frequencies between 500 and 1500 kc is given, and a complete set of curves taken from a transmitting antenna near London is shown. Data is given for aiding in the determination of extent of service area for a broadcasting station.)

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R330 Sutherlin, L. and Upp, C. B. Characteristics of radio receiving tubes. *Electric Jnl.*, **26**, pp. 146–152; April, 1929.

(Gives description of several power tubes and their characteristics.)

R333 Hull, A. W. Hot cathode Thyratrons—Part I. General Electric *Rev.*, **32**, pp. 213–223; April, 1929.

(Three-electrode tube similar to pliotron into which a small amount of inert gas has been introduced. This gas changes the pure electron discharge into an arc so that the Thyratron is an electrostatically controlled arc rectifier. Characteristics of tube are given.)

R342.5 Lamb, J. J. A general purpose audio-frequency power amplifier. *QST*, **13**, pp. 23–28; April, 1929.

(Design and construction data.)

R343 Jarvis, K. W. Radio receiver testing equipment. Proc. I. R. E., **17**, pp. 664–710; April, 1929.

(Detailed description of testing equipment capable of measuring performance characteristics of modern radio receivers with design conforming to the restrictions of the Standardization Committee. A novel modulation meter is described.)

R343 Hendricks, P. S. Another 1929 receiver. *QST*, **13**, pp. 15–18; May, 1929.

(Description of three-tube receiver suitable for frequencies of 2800 to 15,150 kc and also for the 28-megacycle band.)

R357 Greibach, E. H. A new type of precision frequency changer for instrument calibration. *Electric Jnl.*, **26**, pp. 125–126; March, 1929.

(A photoelectric means of producing wide and accurately known variations in the frequency obtained through a standard tuning fork.)

R370 David, P. La qualite de la reproduction radiophonique. (The quality of radiophone reproduction.) *L'Onde Electrique*, **8**, pp. 41–59; Feb., 1929.

(A summary is presented of the factors affecting the quality of radiophone reception discussing (1) distortion due to unfaithful reproduction of frequency and amplitude, (2) distortion due to parasitic frequencies and (3) necessary precautions in detection and in the amplification of audio frequencies. It is concluded that improvement in quality is to be secured at a sacrifice of sensitivity and selectivity in the receiving apparatus.)

R386 Tubbs, E. A. Practical design of audio frequency filters. *Radio* (San Francisco), **11**, pp. 17–18; May, 1929.

(Design data.)

R388 Rangachari, T. S. The super-position of circular motions. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 184–193; April, 1929.

(Derivation of expressions for the superpositions of circular motions such as produced in a cathode-ray tube.)

R500. Applications of Radio

R526.1 Aicardi. Reperage de directions fixes au moyen d'ondes Hertziennes —Radio alignements. (Fixed direction marking by radio waves.) *L'Onde Electrique*, **8**, pp. 20–28; January, 1929.

(A beacon system is described employing the transmission on the same wavelength from two separate antennas. One transmission is slightly modulated. The number and the disposition of the nodal lines in the resultant field are indicated. A practical scheme for periodically displacing these lines to enable the observer to know his position with respect to them is also presented.)

R526.2 Gloeckner, M. H. Der Bordpeilungempfänger im Flugzeug. (The

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radio direction finder applied to aircraft.) *Zeits. für Hochfrequenztechnik*, 33, pp. 92–101; March, 1929.

(Complete description of a special radio direction finder developed by DVL and the Telefunken Co. with an explanation of its application to air navigation.)

R800. Non-Radio Subjects

534 On the sound waves radiated from loud-speakers diaphragms. *Experimental Wireless and W. Engr.* (London), 6, pp. 175–177; April, 1929.

(A review of the radiation of sound waves from commercial types of loudspeakers with special reference to beam effects.)

621.314.6 Hermanspann, P. Untersuchungen an Drosseln mit geschlossenen Hypernik-Kern. (Experiments with Hypernik (iron-nickel-alloy) closed core chokes.) *Zeits. für Hochfrequenztechnik*, 33, pp. 81–84; March, 1929.

(Report of experiments with Hypernik-cored chokes by the Physical Institute of the Technical University at Munich. Measurements of inductance and losses at varying field strengths were taken and compared with those of ordinary dynamo sheet iron. Hypernik is a special alloy of iron and nickel manufactured by the Westinghouse Co.)

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CONTRIBUTORS TO THIS ISSUE

Austin, L. W.: Born October 30, 1867 at Orwell, Vermont. Received A.B. degree, Middlebury College, 1889; Ph.D. degree, University of Strassburg, 1893. Instructor and assistant professor, University of Wisconsin, 1893–1901. Research work, University of Berlin, 1901–1902. With Bureau of Standards, Washington, D. C., since 1904. Head of U. S. Naval Research Laboratory, 1908–1923; chief of Radio Physics Laboratory, 1923 to date. President of the Institute in 1914; served on Board of Direction, 1915–1917; awarded Institute Medal of Honor, 1927. Frequent contributor to the PROCEEDINGS. Associate member, Institute of Radio Engineers, 1913; Member, 1913; Fellow, 1915.

Ballantine, Stuart: Born September 22, 1897 at Germantown, Pa. Operator, Marconi Co., summers 1914–1915; H. K. Mulford Co., bacteriologists, 1916; Bell Telephone of Pa., 1917; expert radio aide, U. S. Navy, in charge of research and development of radio direction-finder apparatus, Philadelphia Navy Yard, 1917–1920; organized Philadelphia Section of the Institute, 1920, and served as chairman until 1926. Studied mathematics at Drexel Institute, 1919, and mathematical physics, graduate school, Harvard University, 1920–1921. With L. M. Hull organized research work at Radio Frequency Laboratories, Boonton, N. J., 1922–1923. John Tyndall Scholar in mathematical physics, Harvard University, 1923–1924. Privately engaged in miscellaneous research work in radio, spectroscopy, astrophysics, propagation of electric waves in the upper atmosphere, at White Haven, Pennsylvania, 1924–1927. In charge of Research Division, Radio Frequency Laboratories, 1927 to date. Frequent contributor to the PROCEEDINGS. Associate member, Institute of Radio Engineers, 1916; Fellow, 1928.

Bogardus, Henry L.: Born December 20, 1894 at Jersey City, N. J. Graduated from Pratt Institute, electrical engineering, 1917. Commercial radio operator, Marconi Co., 1913; radio research laboratory, Western Electric Co., 1917; signal corps, U. S. Army, A.E.F., 1917–1919. U. S. radio inspector, radio division, Department of Commerce, New York, 1920 to date. At present, Acting Supervisor of Radio, New York. Associate member, Institute of Radio Engineers, 1920; Member, 1923.

Crozier, William D.: Born May 24, 1900 at North Liberty, Iowa. Received B.E. degree, University of Iowa, 1923. Graduate student, department of physics, University of Iowa, with research assistantship, 1923–1927. Received Ph.D. degree, 1927. At present research engineer, United Reproducers Corporation, St. Charles, Illinois. Associate member, Institute of Radio Engineers, 1927.

Dean, S. W.: Received A.B. degree, Harvard University, 1919. Cutting and Washington, Inc., 1917; ensign, U. S. Naval Reserve Force, 1918; Radio Corporation of America, 1919–1925; Department of Development and Research, American Telephone and Telegraph Company, 1925 to date, working chiefly in connection with long-wave transatlantic radio receiving systems. Junior member, Institute of Radio Engineers, 1914; Associate, 1918; Member, 1926.

Greaves, V. Ford: Wireless operator, U. S. Navy, 1903; research assistant in physics, Harvard University, 1907–1912; appointed U. S. radio engineer, Department of Commerce, Washington, D. C., 1912–1917, organizing U. S. radio inspection service; lieutenant, U. S. Navy, 1917–1919; director and general

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manager, National Radio Co., San Francisco, Calif., 1919; director, service manager, and assistant general manager, Burnell-Faulkner Automobile Co., Boston, Mass., 1920; general sales agent, Federal Telegraph Co., San Francisco, Calif., 1921–1924; engineer, Magnavox Company, Oakland, Calif., 1924–1927; in charge field work, Argus Research Corporation, also with Jensen Radio Mfg. Co., sales and engineering, 1927–1929. At present chief engineer, United Reproducers Corporation, Newcombe-Hawley Division, St. Charles, Ill.

Harper, Augustus E.: Born December 30, 1896 at Brooklyn, N. Y. Marconi Wireless Telegraph Co. of America, 1917; signal corps, U. S. Army, 1918–1919; Independent Wireless Telegraph Co., 1920. Received M.E. degree, Stevens Institute of Technology, 1922; with Western Electric Co., 1922–1923; Department of Development and Research, American Telephone and Telegraph Company, engaged in work connected with long-wave transatlantic radiotelephony, 1923. Associate member, Institute of Radio Engineers, 1919; Member, 1926.

Kranz, Fred W.: Received A.B. degree, Lawrence College, 1911; M.A. degree, University of Wisconsin, 1919; Ph.D. degree, University of Chicago, 1922; research laboratory, Western Electric Co., 1913–1920; Riverbank Laboratories, Geneva, Ill., 1920 to date. Radio consultant, 1927 to date. Associate member, Institute of Radio Engineers, 1923.

Lack, Frederick R.: Born in England. Engineering department, Western Electric Co., 1913–1917; division of research and inspection, Signal Corps, A.E.F., 1917–1919; installing radio telephone link between Peking and Tientsin, China, 1920–1922; Harvard University, 1923–1925; research department, Bell Telephone Laboratories, 1925 to date. Associate member, Institute of Radio Engineers, 1920.

Manning, Charles T.: Born July 2, 1893 at Madison, N. J. Commercial radio operator, 1911–1913. Inspector and chief inspector, Marconi Wireless Telegraph Company of America for four and one-half years. Instructor at Radio Institute of America for two years; instructor at Marconi Institute for two years; instructor at Y.M.C.A. Radio School for one year. Radio inspector, Department of Commerce, office of supervisor of radio, 1922 to date. Associate member, Institute of Radio Engineers, 1917; Member, 1928.

Marrison, W. A.: Born May 21, 1896 at Inverary, Ont., Canada. Received B.Sc. degree, Queens University, Canada, 1920; M.A. degree, Harvard University, 1921. During the war was wireless mechanic in Royal Flying Corps. Since 1921 has been in the Western Electric Company and Bell Telephone Laboratories working on development of constant frequency sources, studies of quartz crystals as resonators, temperature control, and picture transmission. Member, Institute of Radio Engineers, 1928.

Meissner, Alexander: Born September 14, 1883 at Vienna, Austria. Received degree of Doctor of Technical Science, Vienna Technical School, 1909. In 1922 received degree of Honorary Doctor of Engineering, Technical High School of Munich. Since 1907 with the Telefunken Gesellschaft, and at present head of the research laboratory. Honorary professor, Berlin Technical High School. Member, Institute of Radio Engineers, 1914; Fellow, 1915.

Nakai, Tomozo: Born March 10, 1901 at Fukuyama City, Japan. Graduated electrical department of Osaka Higher Technical School, 1922. Entered radio section of the Electrotechnical Laboratory, Ministry of Communications, Japan, engaged in radio researches. Since 1925 working on wave propagation. Associate member, Institute of Radio Engineers, 1929.

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Wymore, Ivy Jane: Born in Mahaska County, Iowa. Received B.S. degree Drake University, 1918; M.S. degree, George Washington University, 1925. With Division of Metallurgy, Bureau of Standards, 1919–1924; Laboratory for Special Radio Transmission Research, 1924 to date.

Yokoyama, Eitaro: Born July 21, 1883 at Fukui City, Japan. Graduated Engineering College, Tokyo Imperial University, 1908. Entered Ministry of Communications, Japan, engaged in radio researches at the Electrotechnical Laboratory. One of the inventors of the T.Y.K. oscillation gaps for radiotelephony. Chief of Radio Section, Laboratory, 1920. Member, Institute of Radio Engineers, 1917.

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PROCEEDINGS
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The Institute of Radio Engineers

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INSTITUTE SECTIONS

Chairmen	Section	Secretaries
H. P. Thornton	ATLANTA	J. H. McKinney, P. O. Box 1593, Atlanta, Ga.
George W. Pierce	BOSTON	Melville Eastham, 30 State St., Cambridge, Mass.
L. C. F. Horle	BUFFALO-NIAGARA	P. S. March, 428 Richmond Ave., Buffalo, N. Y.
H. E. Kranz	CHICAGO	J. H. Miller, Jewell Electrical Inst. Co., 1650 Walnut St., Chicago, Ill.
Bruce W. David	CLEVELAND	D. Schregardus, Ohio Bell Tel. Co., 750 Huron Road, Cleveland, Ohio
Q. A. Brackett	CONNECTICUT VALLEY	F. C. Beekley, 96 S. Main St., W. Hartford, Conn.
A. B. Buchanan	DETROIT	W. R. Hoffman, 615 West Lafayette Blvd., Detroit, Mich.
Thomas F. McDonough	LOS ANGELES	W. W. Lindsay, Jr., 1348 Club View Drive, Los Angeles, Calif.
Pendleton E. Lehde	NEW ORLEANS	Anton A. Schiele, 1812 Masonic Temple, New Orleans, La.
J. C. Van Horn	PHILADELPHIA	*Acting Secretary* E. T. Darlington, 2848 Idaho Road, Camden, N. J.
L. A. Terven	PITTSBURGH	T. D. Cunningham, 513 Holmes St., Wilkinsburg, Pa.
A. B. Chamberlain	ROCHESTER	A. L. Schoen, 3 Kodak Park, Rochester, N. Y.
Donald K. Lippincott	SAN FRANCISCO	Paul Fenner Custom House, San Francisco, Calif.
Austin V. Eastman	SEATTLE	Abner R. Willson, 8055–14th Ave., N. E., Seattle, Wash.
V. G. Smith	TORONTO	G. E. Pipe, 90 Chestnut St., Toronto, Canada
C. B. Jolliffe	WASHINGTON	J. B. Brady, Ouray Bldg., Washington, D. C.

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C. M. JANSKY, JR.
Member of the Board of Direction, 1929

C. M. Jansky, Jr., was born at Delton, Michigan. In 1917 he was graduated from the University of Wisconsin and in 1919 received the Master's degree in Physics from the same institution. Since January 1, 1920, he has been in charge of instruction in radio engineering at the University of Minnesota and of the operation of the University's broadcasting station. He was a member of the four National Radiotelegraph Conferences. He is associate professor in radio engineering at the University of Minnesota and is practicing consulting radio engineering. Professor Jansky is on the Board of Direction of the American Radio Relay League. He has contributed several papers to the PROCEEDINGS of the Institute of Radio Engineers. In 1928 he was appointed to membership on the Institute's Committee on Standardization. Professor Jansky was elected Manager for a three-year term, beginning 1929. He was elected an Associate member of the Institute in 1918, was transferred to the Member grade in 1925, and the Fellow grade in 1928.

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INSTITUTE NEWS AND RADIO NOTES

1928 Standardization Report

The 1928 Report of the Committee on Standardization, published in the 1929 Year Book, has been reprinted as a separate volume. Members of the Institute may obtain one copy gratis upon application to the Secretary. To non-members the price is one dollar.

Change of Address or Business Title

Members of the Institute are again advised that the Institute office should be notified promptly of any change in mailing address or business title or occupation in order that the PROCEEDINGS may be forwarded promptly to the new address and the Year Book membership catalog kept up to date. The practice of sending forms with the annual ballot, upon which the membership indicates any change in business title, has been discontinued. Accordingly, unless the Institute office is advised otherwise, the 1930 Year Book listing of the catalog of membership will be identical with that of the 1929 book.

On page XXXV of the advertising section of this issue will be found a form which may be used for notifying the Institute office of any change in mailing address or business occupation or title.

Nominations for 1930 Officers and Managers

The Committee on Nominations, Melville Eastham, chairman, is preparing recommendations for the September 4th meeting of the Board of Direction for nominations of officers and elective members of the Board of Direction for 1930.

As set forth in the Constitution, the membership is entitled to make nominations by petition. Such nominations are to be made by letter, addressed to the Board of Direction, setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acceptance, a letter of petition must reach the Board of Direction on or before October 15th and must be signed by at least thirty-five Fellows, Members or Associates.

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There are to be elected a President, Vice President, and two members of the Board of Direction, the latter to serve for terms of three years.

Civil Service Examinations

The U. S. Civil Service Commission announces open competition examinations for the positions of Senior Radio Engineer ($4,600 per year), Radio Engineer ($3,800 per year), Associate Radio Engineer ($3,200 per year), and Assistant Radio Engineer ($2,600 per year).

Competitors will not be required to report for examination at any place but will be rated on their education, training, experience and fitness, such ratings being based upon the competitors' sworn statements in their applications and upon corroborative evidence.

Members of the Institute interested in these positions should communicate with the U. S. Civil Service Commission, Washington, D. C., requesting application form #2600, mentioning announcement #166 and the position for which he desires to compete.

Committe Work

Committee on Bibliography

To investigate the feasibility of the Institute's sponsoring the publication of a complete bibliography on radio and the compilation and publication of a monthly abstract service, President Taylor has appointed the following Committee on Bibliography: B.E. Schackelford, chairman, M. C. Batsel, W. G. Cady, J. H. Dellinger, Melville Eastham, General G. W. Gibbs, C. B. Jolliffe, F. H. Kroger, R. H. Langley, R. H. Manson, Colonel J. O. Mauborgne, Donald McNicol, G. W. Pickard, Haraden Pratt, E. R. Shute, A. F. Van Dyck, H. M. Turner, L. P. Wheeler, H. A. Wheeler, W. C. White, L. E. Whittemore, and W. Wilson.

The Committee held its first meeting at 2 P.M. on June 26th in the office of the Institute in New York City. The following members were present: B. E. Shackelford, chairman, W. G. Cady, Melville Eastham, C. B. Jolliffe, Colonel Mauborgne, H. M. Turner, H. A. Wheeler, and W. C. White.

The Committee made considerable progress in its preliminary work, and will continue to hold meetings throughout the summer in order to submit its report to the Board of Direction early in the fall.

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Institute Meetings

Cleveland Section

On June 11th the Cleveland section held a meeting in the Hotel Statler. This was the annual meeting and was preceded by a dinner. B. W. David, chairman, presided, and forty-seven members and guests attended.

Ralph Worden, radio editor, *Cleveland Plain Dealer*, gave a review of the Chicago Radio Show. A musical program was provided by WTAM Entertainers, which included the Metropolitan Trio.

Los Angeles Section

The Los Angeles section held a meeting, May 28th, 1929. C. S. Breeding, assistant secretary, presided. There were thirty-six members and guests in attendance.

Two papers were presented, one by Professor Harry LaVerne Twining on, "New Developments in Radio Phenomena as Compared with the Einstein Theory" and the second paper by Elbert M. Fox on "Some Experiments on Wave Propagation at High Frequencies."

A general discussion followed the presentation of these papers.

San Francisco Section

On May 21st the San Francisco section held a meeting in the Auditorium of the Pacific Gas and Electric Co., San Francisco, California. Donald K. Lippincott, chairman presided.

S.P.Grace, assistant vice-president of Bell Telephone Laboratories, presented a paper, "Speech Transmission."

A demonstration followed the presentation of the paper. One of the most important features of the demonstrations was the illustration of a method of delayed speech. Mr. Grace said "Hello" at the input end and as late as four and one half seconds later the apparatus said "Hello."

Methods of scrambled voice transmission were put on the loudspeaker to demonstrate the impossibility of understanding it and this was "unscrambled" for the audience.

The regular meeting of the San Francisco section for the month of June was held on the 19th at the Bellevue Hotel, following a dinner at which forty-six members and guests were present.

N. R. Morgan of Stanford University presented a paper on "Power Grid Leak Detection, C Bias Detection and Screen Grid Detectors."

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Following the presentation of the paper L. F. Fuller, Donald Lippincott and a number of members and guests entered into its discussion.

Dr. Fuller presented an outline of his recent trip to the east during which he represented the local section at several Washington meetings.

Personal Mention

R. R. Brewin, of Atlanta, Ga., has been transferred from the engineering department of the Georgia Power Company to the department of radio coordination of the same organization.

George W. Brown, of Atlantic, Mass., is now Manager of the Radio Service Department of the Motor Supply Company of Boston.

E. Finley Carter has resigned from the General Electric Company at Schenectady, where he was in charge of special developments in the radio engineering department, to direct radio-frequency developments for the United Research Corporation located in Long Island City.

G. W. Clark, of Portland, Ore., is now receiving station engineer for the Mackay Radio and Telegraph Company at Honolulu.

William F. Devine, until recently connected in installation on sound projector systems for Electrical Research Products, Inc., of New York City, has moved to London, England, where he has joined the staff of the Western Electric Company, Ltd., as supervisor and inspector in sound projector systems.

Captain E. E. Eiler, for several years director of radio for the Republic of Haiti with headquarters at Port-au-Prince, has been transferred to Marine Barracks, Naval Air Station, Pensacola, Fla.

George L. Haller is now associated with E. A. Myers and Sons of Philadelphia as electrical engineer. Mr. Haller left the employ of the Westinghouse Elec. and Mfg. Company at East Pittsburgh where he was doing radio research work.

Norman R. Hood formerly associated with the Illinois Pipe Line Company at Casper, Wyo., is now radio operator with the Firestone Tire and Rubber Company at Akron, Ohio.

A. C. Matthews, until recently in the radio division of Stewart Warner Corporation at Chicago, has joined the staff of the United Research Corporation at Long Island City, New York, as radio engineer.

F. Cheney Beekley, for a number of years advertising manager and managing editor of *QST* at Hartford, Conn., has resigned to be-

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come associated with the Maxim Silencer Company of Hartford. As advertising manager of *QST* Mr. Beekley has been succeeded by G. Donald Meserve, formerly assistant advertising manager.

Harold L. Olesen has joined the engineering staff of the Jewell Electrical Instrument Company at Chicago. Mr. Olesen was formerly associated with the Fanstell Products Company of North Chicago.

Wallace E. Rushing, until recently operator with the Radiomarine Corporation of America, is now associated with broadcasting station WTIC of Hartford, Conn.

Hoyt S. Scott, for a number of years associated with the Willard Storage Battery Company of Cleveland as radio engineer, is now manager of Radio Engineering Service, Inc., of Cleveland.

F. H. Schnell has been given a year's leave of absence from the Burgess Battery Company of Madison, Wis., to engage in special work for Aero Products, Inc., in Chicago.

M. S. Thacker has joined Siemens Bros. and Company, Ltd. of Bristol, England in the outside contracts department upon leaving Merchants Venturer's College.

Russel S. Turner, recently a student of Dodge Institute at Stoughton, Wis., has joined the Radio Corporation of America at Chicago as radio inspector.

Loren H. Whan, Jr., formerly chief engineer of Miller Welles Company, Inc., of Chicago, is now engineer with the Minerva Radio Company of Chicago.

Harold C. Singleton has resigned from the General Electric Company at Schenectady to enter the employ of the Radio-Victor Corporation of America with headquarters at San Francisco.

John L. Barnes, upon completion of a five-year coordination communications course given at the Massachusetts Institute of Technology with the Bell System, has been appointed a Fellow in mathematics at the Princeton Graduate School.

R. F. Durant, A.F.C., formerly Radio Branch, Royal Air Force, has left to take up an appointment with Civil Aviation Radio, Air Ministry, London.

C. I. Soucy, until recently engaged in talking motion picture installation as inspection engineer, has assumed the new position of service superintendent with the Research Products, Engineering Department, of the Northern Electric Company, Ltd., of Canada.

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GEOGRAPHICAL LOCATION OF MEMBERS ELECTED JULY 3, 1929

For Election to the Associate Grade

California	Bolinas	Baker, Thomas S.
	Bolinas, Radio Corporation of America	Clark, Robert W.
	Bolinas	Riddle, Elmer R.
	Hollywood, 1719 N. Gardner St.	Blackburn, John F.
	Huntington Park, 6608½ Rugby St.	Hudson, T. L. W.
	Jackson, 115 Court St.	Snyder, W. Gilman, Jr.
	Los Angeles, 425 S. Bonnie Brae	Dixon, A. L.
	Los Angeles, 451 North Hill St.	Haas, Clarence H.
	Los Angeles, 5533 Hollywood Blvd.	Wright, James L., Jr
	Menlo Park, Box 163	Seal, H. Robert
	Palo Alto, Federal Telegraph Co.	Beatty, W. E.
	Palo Alto, 515 Oberlin Ave.	Lawrence, Robert B.
	Palo Alto, Federal Telegraph Co.	Suydam, C. H.
	Rosemead, 1223 S. Earl St.	Turner, W. E. H.
	Sean Pedro, USS *New Mexico*	Ruble, W. J.
Colorado	Dnver, 2041 S. Josephine	Scheneman, Henry W.
Delaware	Wilmington, 418 S. Grant Ave.	Smyth, Earle
Dist. of Columbia	Washington, 621 G Street, S. W.	Appich, Wm. H.
	Washington, 3541 Holmead Pl., N. W.	Bradford, Henry K.
	Washington, 4637 Brewer Pl., N. W.	Burke, James W.
	Washington, Bureau of Standards	McIlwraith, Charles G.
	Washington, 1123 East Capitol St.	Simon, Isaac B.
	Washington, 1814 Jackson St.	Stevens, Waldo W.
Georgia	Columbus, Box 69	Kirkland, A. H.
	Columbus, Sta WRBL	Shaffer, C. Robert
	Fort Benning, Headquarters Battery	Tate, Robert L.
Illinois	Chicago, 6429 S. May St.	Ellis, Robert M.
	Chicago, 1900 Mohawk St.	Fritzel, Joseph
	Chicago, 7614 Essex Ave.	Levy, Samuel L.
	Evanston, 139 Custer Ave.	Stein, Harold A.
Indiana	Anderson, 1219 Home Ave.	Miller, Louis
	Ashley	Urey, Geoge M.
	Sweetser	Myers, Delbert
	Vernon, Box 24	Dausch, Elmer F.
Louisiana	New Orleans, 3111 Louisiana Ave. P'kway	Chateau, Arthur
	New Orleans, 512 St. Peter	Elkins, W. P.
	New Orleans, 1716 Painter St.	Peters, C. W.
Massachusetts	Cambridge, 7 Kirkland St.	Batchelder, L.
	Lexington, 16 Cliff Ave.	Chute, Dudley H.
	Lowell, 722 E. Merrimack St.	Coburn, E. D.
	New Bedford, 373 Pleasant St.	Meredith, W. B
	Roxbury, 25 Fernboro St.	Katz, Louis S.
	Springfield, 28 Saratoga St.	Davis, William G.
Michigan	Detroit, 9125 Avis Ave.	Anderson, Donald T.
	Detroit, 8881 Lauder Ave.	Jackson, Paul
	Detroit, 2923 Kirby W.	Kirby, Otto I.
	Detroit, 5842 Vernor Hgy West	Pennebaker, R. T
	Lansing, 325 Smith Ave.	Wells, Lawrence V.
	Muskegon, 329 Merrill Ave.	Owens, Robert F.
	Sault Ste Marie, SS *M. A. Bradley*	George, Edward M.
Missouri	Kansas City, 3315 Holmes St.	Coates, B. Franklin
	Springfield, 906 East Grand	Moss, Terry L.
	St. Louis, 3328 Louisiana Ave.	Althoff, Frederick E.
	St. Louis, 5468 N. Kingshighway Blvd.	Cook, Jesse A.
	St. Louis, 3631 Bamberger Ave.	Proehl, Robert O.
Montana	Butte, 1120 West Gold St.	Walker, Raymond E.
New Jersey	Bloomfield, 18 Austin Place	Weaver, Karl S.
	Boonton, 302 Dawson Ave.	Cordell, Peter C.
	Collingswood, 106 Fern Ave.	Richards, Horace J.
	Deal, Box 122	Kerwien, Arthur E., Jr.
	Irvington, 41–42 St.	Coman, George E.
	Long Branch, 58 Washington St.	Emerson, Kenneth H.
	Merchantville, 606 W. Maple Ave.	Closson, Luke E.
	Newark, 820 Mt. Prospect Ave.	Canfield, Wilson R.
	Newmark, 180 Runyon St.	Dauber, Arthur O. F.
	Roselle, 133 Vine St.	Bosler, Gustave A.
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Part II

TECHNICAL PAPERS

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 8 *August, 1929*

THE MUTUAL IMPEDANCE BETWEEN ADJACENT ANTENNAS*

By

CARL R. ENGLUND AND ARTHUR B. CRAWFORD
(Bell Telephone Laboratories, Inc., New York City)

Summary—*The simple theory for the computation of reflecting or multibranch antenna systems is sketched. If the points at which observations of electrical quantities are to be made are definitely specified, a knowledge of the self and mutual impedances (properly defined) between antennas is sufficient to make the computations determinate. Of the circuit constants, the most useful and accessible is the antenna current ratio*

$$K_{12}=\frac{I_2}{I_1}=K_0e^{i(\phi-(2\pi d/\lambda))}$$

and in the work here reported ϕ has been measured in the range 0.33λ to 1λ. Experiment has shown that in this range ϕ is that theoretically calculable for a Hertzian doublet. Actually this range is equivalent to λ/3 to ∞. The discussion of experimental procedure is purposely thorough.

INTRODUCTION

In this paper a start is made at putting the mutual antenna relation in circuit theory form by the aid of experimental procedure. The discussion is limited to parallel rectilinear antennas in free space, the centers of which are in a common plane, and it is postulated that all current or impedance measurements are to be made by opening this central point.

THEORY

The usual method of treating "concealed" circuits, of which this is an application, may be developed as follows. Given two accessible terminal pairs (as in Fig. 1), we define the positive current direction for each terminal pair in an arbitrary manner, for example as shown, then apply an emf at (1) and measure the resultant current at (1) and the voltage at (2), the secondary terminal being open. We have then by direct measurement,

$$Z_1=\frac{E_1}{I_1}, \quad Z_{12}=\frac{E_2}{I_1}, \quad I_2=0 \tag{1}$$

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Next we reverse the terminals and repeat. We have then

$$Z_2=\frac{E_2}{I_2}, \quad Z_{21}=\frac{E_1}{I_2}, \quad I_1=0 \tag{2}$$

and with these four quantities we uniquely define the network for all currents and voltages.

Thus when for open secondary circuit we write $E_1=Z_1I_1$, the closure of the secondary results in a secondary current I_2 which, in turn, introduces in the primary circuit a voltage of $Z_{21}I_2$ so that the new primary

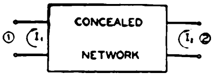

Fig. 1

current is given by $E_1+Z_{21}I_2=Z_1I_1$. At the same time the voltage induced in the secondary circuit by the primary current is all absorbed by the secondary impedance drop or $Z_{12}I_1=Z_2I_2$. Rewriting these expressions in symmetrical form gives

$$\left.\begin{aligned} E_1&=Z_1I_1-Z_{21}I_2\\ 0&=-Z_{12}I_1+Z_2I_2 \end{aligned}\right\} \tag{3}$$

from which we obtain, by solution and definition,

$$\left.\begin{aligned} I_1&=\frac{E_1}{S_1}=E_1\frac{Z_2}{Z_1Z_2-Z_{12}Z_{21}}\\ I_2&=\frac{E_1}{S_{12}}=E_1\frac{Z_{12}}{Z_1Z_2-Z_{12}Z_{21}}\\ \frac{I_2}{I_1}&=K_{12}=\frac{Z_{12}}{Z_2}=\frac{S_1}{S_{12}} \end{aligned}\right\} \tag{4}$$

If we transfer these operations to the secondary side, we have a second set of similar expressions

$$\left.\begin{aligned} I_2&=\frac{E_2}{S_2}, \quad \frac{I_1}{I_2}=K_{21}=\frac{Z_{21}}{Z_1}=\frac{S_2}{S_{21}}\\ I_1&=\frac{E_2}{S_{21}} \end{aligned}\right\} \tag{5}$$

The most readily measured quantities are the self impedance ones Z_1, Z_2, S_1, and S_2, but they are not sufficient for a determinate theory. We must also measure a pair of mutual impedances (Z_{12}, Z_{21}) or a pair of

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transfer impedances (S_{12}, S_{21}). For ordinary wire circuits it is readily demonstrable that

$$\left.\begin{aligned} Z_{21} &= Z_{12} \\ S_{21} &= S_{12} \end{aligned}\right\} \tag{6}$$

and it has recently been shown[1] that the same is true, with reservations unimportant here, for the antennas of radio technique.

In the radio applications of the above we are chiefly interested in the values of the currents flowing in the several antennas, in particular in the ratios I_1/I_0, I_2/I_0, $\cdots$, etc., where we relate phase and amplitude of any current to one fiducial current of the system, and it is the chief purpose here to discuss the determination of the current ratio for a single pair of mutually influencing antennas.

Assume, therefore, two mutually influencing antennas, in the center of one of which an emf is introduced. Equations (3), (4), and (5) apply directly and we have

$$S_1 = \frac{Z_1 Z_2 - Z_{12} Z_{21}}{Z_2} = Z_1(1 - K_{12} K_{21})$$

whence

$$K_{12} K_{21} = \frac{Z_1 - S_1}{Z_1}$$

or since

$$K_{21} = K_{12} \cdot \frac{Z_2}{Z_1}, \quad K_{12} = \sqrt{\frac{Z_1 - S_1}{Z_2}} \cdot \tag{7}$$

Of these four quantities a measurement of three will be necessary to determine the fourth except in the case of identical antennas. Then $Z_1 = Z_2$, by symmetry, and $K_{12} = \sqrt{1 - S_1/Z_1}$ so that the determination of K_{12} can be made directly by a pair of a.c. bridge measurements[2] on one antenna, the second being alternately present and absent.

Obviously the ratio

$$\left| \frac{I_2}{I} \right| = | K_{12} | \tag{8}$$

[1] Carson, John R., *Bell Sys. Tech. Jour.*, **3**, 393; 1924, and PROC. I. R. E., **17**, 952; June, 1929.

[2] Another special case is mentioned by Breit, Sci. Paper No. 430, Bur. of Stand. 1922, and by Wilmotte *Jour.* I.E.E. **66**, 961; 1928.
Here $K_{12} = 1/K_{21}$ or $K_{12}^2 = S_1/S_2 \cdot S_{21}/S_{12}$ or $K_{12} = \sqrt{S_1/S_2}$.

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is immediately determinable by means of a pair of ammeters but arg I_2/I_1 is not so obtainable. Any method of simultaneously conveying, by metallic conductors, currents from the two antennas to a common point for phase comparisons is open to the objection that the physical connections introduce errors unknown or difficult of control, and the conductors can act as antennas themselves. A straightforward radiation comparison is immune to these errors, but lacks the independent phase and amplitude control of the wire method.

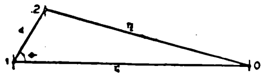

Fig. 2

We may consider the following radiation experiment. An antenna (1) is driven by a generator and has a reflector or parasitic antenna (2) in its immediate neighborhood. The spacing between, and orientation of the line joining them are variable and the field is observed at substantially radiation distance by a third antenna (0) supplied with current indicating apparatus. The geometry will be as in Fig. 2 where

$$r_1 \gg d$$

$$r_2 \gg d.$$

Now with r_1 and r_2 large compared with the wavelength used,[3] the radiated electric field will have the same space variation with r as for a simple Hertzian doublet, and will be strictly proportional to the currents as measured in the radiating antenna centers. Moreover, the resulting receiver antenna current will be proportional to the resultant electric field at its location, the reaction of the receiver current upon the driving antenna being negligible. Accordingly, we may write for the receiver antenna current, if we drop the factor $e^{i\omega t}$,

$$I = C\left[\frac{h_1 I_1}{\lambda r_1} e^{-i(2\pi r_1/\lambda)} + \frac{h_2 I_2}{\lambda r_2} e^{-i(2\pi r_2/\lambda)}\right]$$

where C is the complex constant of proportionality, I_1 and I_2 the current amplitudes, and h_1 and h_2 the effective antenna heights. Putting in the current ratio gives,

$$I = \frac{CI_1}{\lambda}\left[\frac{h_1}{r_1} e^{-i(2\pi r_1/\lambda)} + K_{12}(h_2/r_2) e^{-i(2\pi r_2/\lambda)}\right] \qquad (9)$$

[3] A distance of 5 wavelengths to the nearest antenna is ample to meet this condition; the spacing d can hardly exceed 2 wavelengths and leave a workable antenna reaction.

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In radiation theory it is advantageous to "back date" all phenomena to a common source; we therefore put

$$K_{12}=K_0e^{i(\phi-(2\pi d/\lambda))} \tag{10}$$

where $K_0=|K_{12}|$ and the receiver current becomes

$$I=\frac{CI_1h_1}{\lambda r_1}e^{-i(2\pi r_1/\lambda)}\left[1+K_0\frac{h_2}{h_1}\cdot\frac{r_1}{r_2}\cdot e^{-i[2\pi/\lambda(r_2+d-r_1)-\phi]}\right] \tag{11}$$

Of this we can observe directly only $|I|$; forming this gives

$$|I|=I_0=\frac{|C|\,I_1h_1}{\lambda r_1}\sqrt{1+\left\{K_0\frac{h_2}{h_1}\cdot\frac{r_1}{r_2}\right\}^2+\frac{2K_0h_2r_1}{h_1r_2}\cos\left[\frac{2\pi}{\lambda}(d+r_2-r_1)-\phi\right]} \tag{12}$$

This expression is difficult to evaluate in absolute magnitude, directly. However, since it is possible to determine K_0 rather simply, and the configuration may be changed arbitrarily, the remaining unknown ϕ is determinable in several manners.

With both K_0 and ϕ depending on d an advantageous manner of altering the configuration is to hold d constant and vary θ. We have then

$$r_2^2=r_1^2+d^2-2r_1d\cos\theta \tag{13}$$

and the current expression becomes

$$I_0=\frac{|C|\,I_1}{\lambda}\cdot\left\{\frac{h_1}{r_1}\right\}\cdot\sqrt{1+\frac{K_0^2\left\{\frac{h_2}{h_1}\right\}^2}{1+\left\{\frac{d}{r_1}\right\}^2-\frac{2d}{r_1}\cos\theta}+\frac{2K_0\frac{h_2}{h_1}}{\sqrt{1+\left\{\frac{d}{r_1}\right\}^2-\frac{2d}{r_1}\cos\theta}}\times\cos\left[\frac{2\pi r_1}{\lambda}\left\{\frac{d}{r_1}-1+\sqrt{1+\left(\frac{d}{r_1}\right)^2-\frac{2d}{r_1}\cos\theta}\right\}-\phi\right]} \tag{14}$$

and when $r_1\gg d$

$$I_0=\frac{|C|\,I_1}{\lambda}\frac{h_1}{r_1}\sqrt{1+\left(\frac{K_0h_2}{h_1}\right)^2+2K_0\frac{h_2}{h_1}\cos\left[\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi\right]} \tag{15}$$

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As a function of θ it is evident by inspection that the maxima of this expression occur when the cosine term is a maximum; this maximum may be an absolute or a relative maximum. An absolute maximum occurs when

$$\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi=2n\pi \tag{16}$$

with $n=0, 1, 2, \cdots$, etc., and the cosine term becomes unity. A relative maximum occurs when the cosine term approaches unity but does not reach it before receding again. Only absolute maxima yield determinations of ϕ; relative maxima occur only at $\theta=\pi$, and are geometrical rather than electrical in character. No maximum obtained at $\theta=\pi$ is therefore usable. Furthermore a minimum value of d exists below which absolute maxima are unobtainable and the evaluation of ϕ impossible by this method. The greater ϕ is, the greater is this minimum distance.

Absolute minima occur equally with the corresponding maxima, the condition for their existence being $2\pi d(1-\cos\theta)/\lambda-\phi=(2n+1)\pi$ with n taking the same values as before.

It is not difficult, practically, to satisfy the condition $r_1 \gg d$ but the experimental procedure itself is not without difficulty. Thus at the very short wavelengths ($\lambda<6$ meters) where the manipulation itself is practicable the power leads and apparatus carry very disturbing currents which may introduce serious errors in the phase angle as determined. A rough criterion of safety in this respect is to demonstrate that the polar characteristic of the transmitter electric field is a circle. The work reported by Tatarinoff[4] (the only similar work so far noticed) was performed indoors and is therefore open to question. Only a small amount of experimentation is necessary to demonstrate the sensitivity of such experiments to neighboring conductor systems.

Another, and general, question concerns the antennas themselves. If a pair of rectilinear rods of equal length are operated at their natural period a very definite specification of such antennas is possible. This is not a workable case in general, however, it being usually necessary to shorten the antenna so as to allow the insertion of coupling inductances. The radiation resistance is thus lowered and the antenna resonance sharpened so that deliberate tuning is required, and the experimental observations must be carried out with the antenna properly tuned. There is no evident reason, however, why a K_0 and ϕ thus determined cannot be applied to a pair of half wavelength rods without serious correction.

[4] "Zur konstruction der Radio Spiegel," *Jahr. d.D.T.u.T.*, **28**, 117; 1926.

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A modification of (7) gives another method of varying the configuration. This is to choose some workable pair of θ and d values and then alternately place and remove the reflector antenna. Minus the reflector antenna we have $I_{0m}=\{|C|/\lambda\}\cdot\{h_1/r_1\}\cdot I_{1m}$ and with the reflector antenna we have (15), so that by division,

$$\left\{\frac{I_{1m}I_0}{I_1I_{0m}}\right\}^2=1+\left\{K_0\frac{h_2}{h_1}\right\}^2+2K_0\frac{h_2}{h_1}\cos\left[\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi\right]$$

or when the antennas are alike in effective height

$$\left\{\frac{{}_{1m}I_0}{I_1I_{0m}}\right\}^2=1+K_0^2+2K_0\cos\left[\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi\right]$$

and

$$\phi=\frac{2\pi d}{\lambda}(1-\cos\theta)-\cos^{-1}\left[\frac{\left\{\frac{I_{1m}I_0}{I_1I_{0m}}\right\}^2-1-K_0^2}{2K_0}\right] \qquad (17)$$

with only known quantities on the right-hand side. This method should be especially suitable at small values of d. The indicated current ratios require merely two separate deflections on a "square law" meter; the ratio $K_0=|I_2/I_1|$ on the other hand is that of two different meters and will have to be evaluated in absolute measure. This is the chief experimental difficulty at short wavelengths. Notice that if we make $r_1=r_2$ we may use (12) directly and need not locate the receiver at a great distance. The equation for ϕ will be (17) with $\cos\theta=0$.

Equation (15) will give radial maxima, as d is varied, which are simpler to observe experimentally than the angular ones with θ, already mentioned, since they are more sharply defined thus. But the reduction of the results is more difficult since both K_0 and ϕ are functions of d, and although $K_0(d)$ can be separately measured this is not sufficient additional information. Obviously the radial maxima as functions of θ will be a slightly different set of curves from the angular maxima as functions of d, the latter lying outside of and enclosing the former. This is readily seen to be the case, for as we move the reflector antenna radially towards the transmitter antenna from a point on the angular maxima curve, the dephasing action, due to wrong location, is, for a certain decrease in d, compensated for by a corresponding increase in reflector current, and the maximum will lie where the dephasing effect and current rise just cancel. This will be most noticeable for small values of d; for large values the two types of maxima (or minima) move towards coincidence. If the transmitter antenna itself determines the

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generator frequency, a radial motion of the reflector antenna will noticeably affect the generator frequency. However, the sharpness of a radial maximum is such that serious error is not introduced in this manner.

Another procedure for obtaining angular maxima is to move the reflector antenna from the transmitter to the receiver antenna, and while this is advantageous in the fact that receiver apparatus is much

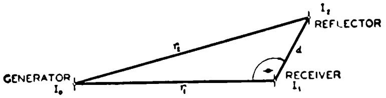

Fig. 3

more compact and simple than transmitter apparatus, the theory becomes more complicated. In the transmitter-reflector case the distant antenna action was negligible while in the receiver reflector case the distant antenna action is the driving field itself. We now have the geometry of Fig. 3 and the equations

$$\left.\begin{aligned} Z_{01}I_0 &= Z_1I_1 - Z_{21}I_2 \\ Z_{02}I_0 &= -Z_{12}I_1 + Z_2I_2 \end{aligned}\right\} \tag{18}$$

from which we have

$$I_1 = I_0\frac{Z_{01}Z_2 + Z_{02}Z_{21}}{Z_1Z_2 - Z_{12}Z_{21}}.$$

Substituting the current ratio values of (4) and (5) turns this into

$$I_1 = I_0K_{01}\frac{1 + \dfrac{Z_1}{Z_2}\cdot\dfrac{Z_{02}}{Z_{01}}K_{21}}{1 - K_{12}K_{21}}. \tag{19}$$

When r_1 and r_2 are relatively large we may fall back on the Hertzian doublet expression for the driving field at the receiver antennas and have

$$Z_{02} = C_2\frac{-i60\pi h_0}{\lambda r_2}e^{-i(2\pi r_2/\lambda)} \tag{20}$$

where C_2 is the effective height of the antenna, defined as the voltage appearing in antenna center divided by the field producing it. A similar expression holds for Z_{01}, and forming the ratio of these two gives

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$$\frac{Z_{02}}{Z_{01}}=\frac{C_2}{C_1}\cdot\frac{r_1}{r_2}\cdot e^{-i(2\pi/\lambda)(r_2-r_1)}$$

and the current expression becomes

$$I_1=I_0K_{01}\frac{1+\frac{Z_1}{Z_2}\cdot\frac{C_2}{C_1}\cdot\frac{r_1}{r_2}e^{-i(2\pi/\lambda)(r_2-r_1)}K_{21}.}{1-K_{12}K_{21}}. \tag{21}$$

Comparing this with (11) we see that instead of the sum of two vectors we have the quotient of two such sums and the unraveling, for radial maxima, of experimental observations to give K_0 and ϕ is doubtless more difficult. On the other hand angular maxima involve only the numerator, and (15) can be applied almost unchanged.

Experimentally there is still a difference, however, since with the reflector adjacent to the generator the receiver antenna system is immaterial and the deflecting meter can be carried to any favorable situation by means of a pair of wires and read with ease, while for the reflector adjacent to the receiving antenna no such procedure is permissible and the meter must be read at a distance by a telescope. But it should be easier to make the two antennas identical in the latter case. Then since

$$\begin{cases} K_{12}=K_{21}=K_0e^{i(\phi-2\pi d/\lambda)} \\ Z_1=Z_2 \\ C_1=C_2 \end{cases}$$

we have

$$I_1=I_0K_{01}\frac{1+\frac{r_1}{r_2}K_0e^{-i[(2\pi/\lambda)(r_2+d-r_1)-\phi]}}{1-K_0{}^2e^{-2i(2\pi d/\lambda-\phi)}} \tag{22}$$

and

$$\left|\frac{I_1}{I_0}\right|=|K_{01}|\sqrt{\frac{1+\left\{\frac{r_1}{r_2}K_0\right\}^2+2\frac{r_1}{r_2}K_0\cos\left[\frac{2\pi}{\lambda}(r_2+d-r_1)-\phi\right]}{1+K_0{}^4-2K_0{}^2\cos 2\left(\frac{2\pi d}{\lambda}-\phi\right)}}. \tag{23}$$

The procedure involved in (17) is less readily usable for receiver-reflector experiment, owing to the power required for direct meter operation.

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Since ϕ can be calculated for a Hertzian doublet and since the Hertzian doublet has played an important role in radio theory, it is of interest to compare this calculated value with the experimental values for finite antennas. The "median plane" electric field of a Hertzian doublet is given by

$$E^* = -\frac{30hI_0}{d}\left(\frac{i\omega}{c}+\frac{1}{d}+\frac{c}{i\omega d^2}\right)e^{i\omega(t-d/c)} \tag{24}$$

when the doublet current is assumed as $I = I_0 e^{i\omega t}$. This expression is most conveniently written as

$$E = \frac{60\pi h}{d\lambda} I_0 K e^{i\omega(t-d/c)+i\psi} \tag{25}$$

where

$$K = \sqrt{1-\left(\frac{\lambda}{2\pi d}\right)^2+\left(\frac{\lambda}{2\pi d}\right)^4} \quad \text{and} \quad \psi = \tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)+\pi$$

ψ being the angle of lead of E over I. The values of K and ψ as functions of d/λ are attached in the curves of Figs. 4 and 5. The application

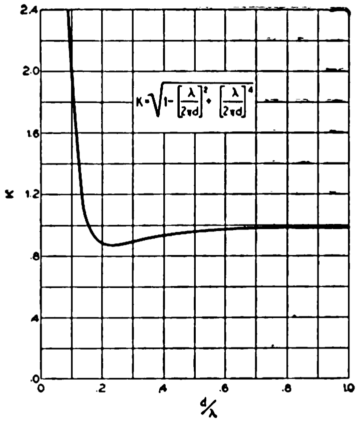

Fig. 4

of (12) gives for the equiphase lines, where a reflector antenna with cophased current would affect a distant receiver in phase with the transmitter current

* The units used are amperes, volts per cm, and centimeters, to conform with the rest of the paper. $c = 3\times10^{10}$ cm = vel. of light.

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$$\frac{2\pi}{\lambda}(r_2+d-r_1)-\tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)=(2n+1)\pi$$

and when the receiver moves to infinity

$$\frac{2\pi d}{\lambda}(1-\cos\theta)-\tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)=(2n+1)\pi.$$

The antiphased lines occur for even multiples of π, Fig. 6 gives the first two cophased and the first antiphased lines.

Experimental

An experimental study of the maxima and minima of (15) and (23) has proved to be more difficult than was anticipated. All moving conductors, animate or inanimate, such as pedestrians and automobiles,

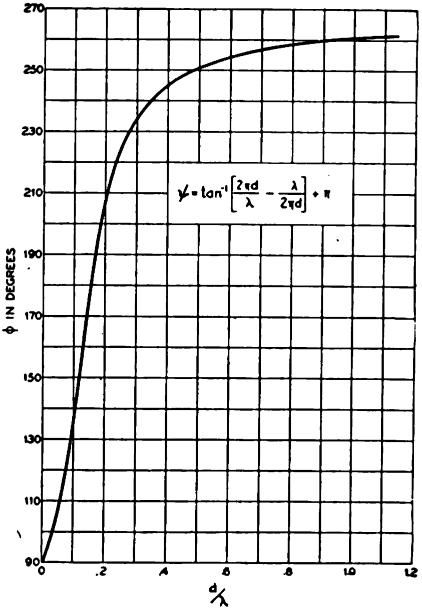

Fig. 5

definitely prevent readings when within some 50 meters (app. 12 wavelengths) of the generator-receiver system. The system actually functions as an automatic detective apparatus, the meter oscillations betraying at once any human movement within the 50-meter range. This movement passes through a cycle every time the pedestrian has altered, by a whole wavelength, the generator-pedestrian-receiver ether path. In the same manner activity by the operator masks the

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true maxima and minima settings, and it is necessary for the operator to remain immobile at a distance.

As stated earlier the effect of immobile neighboring conductors is to produce a serious error in the measured value of ϕ. For suppose, in Fig. 2, a conductor located between antennas (1) and (0) and so disposed as to carry a current when the generator antenna (1) is excited. The field from this current superposes at (0) on the field from (1), and in general the vector sum will have a different phase from that of the component arriving from (1). But the component arriving from (1) is the one with which the phase of the (2) field component is to be com-

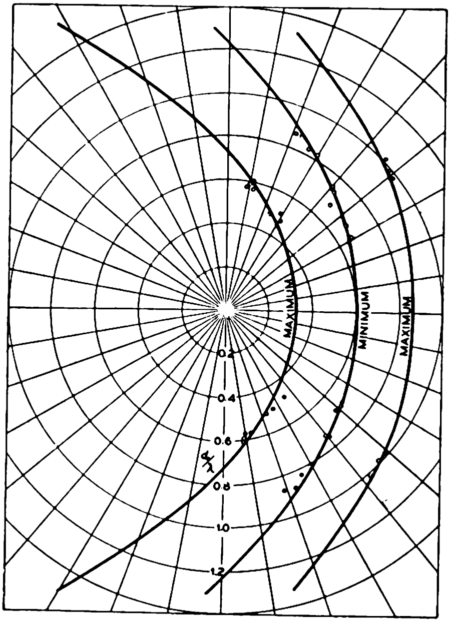

Fig. 6

pared, and if the immobile conductor carries considerable current or is near to (0) a bad error will be introduced. Since the main exciting field arises from the generator antenna current, which always considerably exceeds the reflector current, this error is likely to be very nearly a constant one.

For angular maxima determinations the most serious source of error arises in the mistuning of the reflector antenna, a fact early discovered experimentally. In order to make experiment definite it is necessary to fix on a standard relation between the ether electric field and the reflector antenna current produced by it. This relation is preferably

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that of cophasing. The reactance of the reflector is then zero and the current and field phases are identical. Various methods of setting a correct tune were tried. If the reflector is tuned, when near a maximizing position, by observing the receiver meter, the angle θ then varied to improve the maximum, the antenna retuned, θ readjusted and so on, the correct tune should be obtained in the limit. Possibly owing to the unavoidable effect of the operator on the tuning of the antenna the method proved unsatisfactory. On the other hand, the same process applied to radial maxima determinations proved satisfactory.

The next method tried was that of observing the receiver current as the reflector condenser was varied over its scale. If θ is off on one

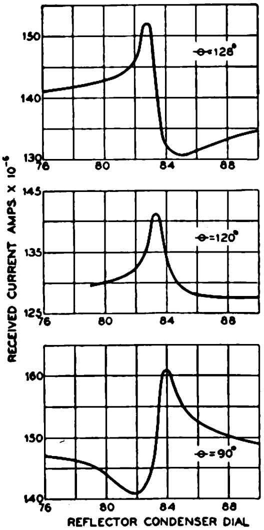

Fig. 7

side of the proper value the resulting resonance curve is characteristically unsymmetrical; if θ is off on the other side the same resonance, but with a mirror inversion, results; with θ correct the resonance curve becomes symmetrical. These curves, one of which is given in Fig. 7, checked properly with the theory. However, the accuracy of tune was again insufficient.

Another method of obtaining a reflector tune is by observing its effect on the generator tune, itself due to the transmitter antenna constants. A very sensitive one, too sensitive in this case, is to note the generator frequency variation as an audible beat with a second oscillator. Theoretically, positions can be found where the reflector at

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exact resonance (reflector reactance zero) can introduce only resistance into the generator circuit,[5] and if the resultant coupling is not too great this introduced resistance will only slightly affect the generator frequency. Under these circumstances the beat note will be identical with that when the reflector antenna is removed to infinity. This method was quite unworkable here, the frequency change being some 70 kc. However, the wavemeter used[6] was very sharply selective and would indicate a frequency change of 1 part in 2000 without trouble and seemed available. The results were again not encouraging and this method was abandoned.

A meter in the center of the reflector antenna will indicate resonance but not without a certain error. Thus if we write for the reflector current

$$I=\frac{E}{R+iX}, \quad I_0=\frac{E}{R}$$

we have

$$\frac{|I|}{I_0}=\frac{R}{\sqrt{R^2+X^2}}=1-K$$

where K is the fractional drop in the current off tune. Further, arg $\{I/E\}=-\delta=-\tan^{-1}X/R$ and from this we obtain the table

K	δ
0.005	5.74 deg.
0.01	8.11 "
0.015	9.94 "
0.02	11.48 "
0.03	14.07 "
0.04	15.78 "
0.05	18.18 "

and for a given value of K, detectable in the reflector meter reading, the phase angle variation over which the observations may lie is twice the corresponding δ. Tuning at a distance of 1.5 meters and reading a sluggish meter is unlikely to give values of 2δ less than app. 12 deg. This error must be countered by averaging numerous observations.

It is, of course, not necessary to have driving field and reflector current in phase provided we know their phase difference. Thus we may tune for 0.7 of the resonance current, on either side, where resistance equals reactance and $\delta=45$ deg. Two advantages seem present, viz.: the steeply rising resonance curve makes an accurate setting possible, and, by tuning on the lagging side, some of the lead of ϕ may be cancelled allowing measurements on a smaller value of the radius d. The feasibility of this method is yet to be tried.

[5] For two Hertzian doublets the first two positions are $d=0$, $d=0.713\lambda$.
[6] Described in *Bell System Tech. Jour.*, 7, 417; 1928.

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Lastly, the setting of θ is not an accurate process. The change in receiver current per degree of rotation of receiver antenna is almost unobservable, and when masked by vibrations produced by ever present winds is a difficult measurement. Again an average of a number of readings becomes necessary.

For radial maxima the procedure of plotting current vs. distance curves is easily accurate enough for radii in back of the operating antenna. Radii approaching right angles do not have as sharp maxima

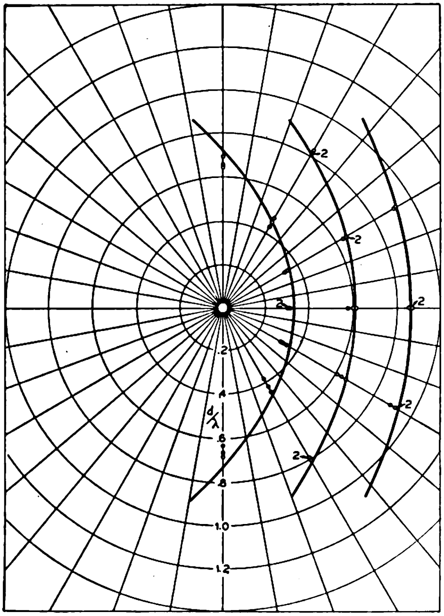

Fig. 8

however. As mentioned earlier either method is good for large values of d/λ, only the angular maxima are accurate for the smaller d/λ values.

The experimental arrangement, pictured in Figs. 11 and 12, consisted of a generator and a receiver each mounted on tripods so as to bring the centers of the (always vertical) antennas 2.5 meters above ground. The generator used a UX852 tube,[7] had a frequency range of 4 to 8 meters, and was battery driven, the power wires being led out horizontally for a distance of 7 meters before dropping to the battery

[7] Substantially the same generator as shown in *Bell System Tech. Jour.*, 7, 408; 1928.

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cabinet. Two filters separated this power cable into three parts. The plate power averaged 540 volts×0.05 ampere.

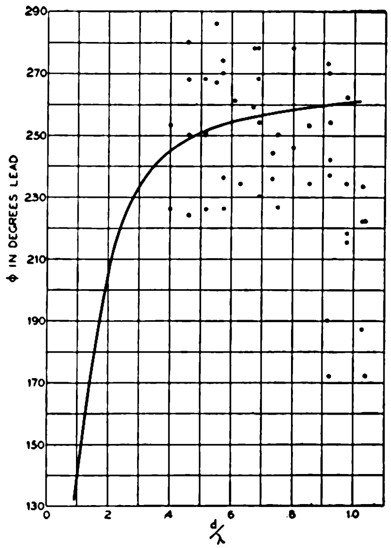

Fig. 9

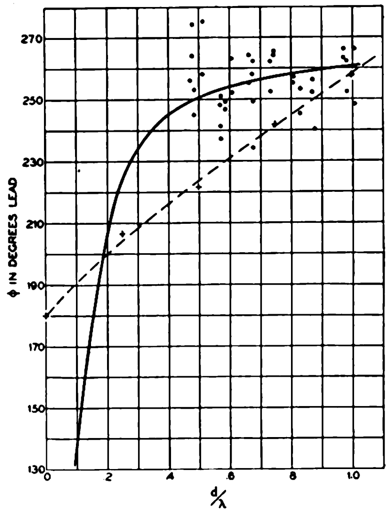

Fig. 10

The receiver was a simple "push pull" vacuum-tube voltmeter using two 215A "peanut" tubes with a microammeter in their common plate

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lead and was stationed at approximately 31 meters from the generator. The reflector antenna was mounted either on a radial carriage and track or on a rotating arm, both operated at a distance by means of a cord and pulley system. All three antennas were as nearly identical as possible, and were each tuned by means of a small three turn, 4.7 cm diameter, copper tube inductance unit with cutdown Remler condenser connected across it, this antiresonant circuit being mounted in the center of the antenna. The overall antenna length was 106.6 cm or approximately 52 per cent of the corresponding half wavelength resonator. The wavelength used varied slightly from day to day, averaging 4.34 meters.

The first results obtained were radial (receiver) maxima, and were found by plotting radial distance versus receiver current curves and locating the maxima and minima graphically. The operator sitting at a distance of seven meters read the receiver current by means of a field

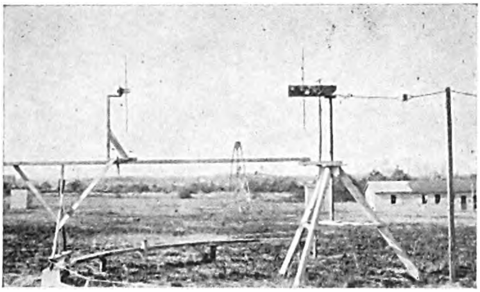

Fig. 11

glass. These maxima and minima are plotted in Fig. 8, the circles being observed values and the full curves the theoretical Hertzian doublet co- and antiphase lines of Fig. 6. The fit is within experimental error; moreover, the first observational maxima values lie, correctly, between the first cophase line and the generator point.

The next results were obtained by means of angular maxima about the generator, the receiver current being carried back to the operator by leads lying on the ground. Meanwhile experiments leading to the determination of a definite tune were carried out. The results are plotted in Fig. 9, the circles being observations, and the continuous curve the theoretical Hertzian doublet phase angle. The scattering is marked, since all results are included irrespective of method of tune. In Fig. 10 the tuning has been done as carefully as possible by means

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of a reflector antenna ammeter[8] and the scattering much reduced. As mentioned earlier, it is to be expected that the dispersion will cover a 12 deg. band.

The observations of Fig. 10 are plotted on Fig. 6, and the fit of experiment with theory is again close. Since the theoretical Hertzian doublet expressions will be unquestionably valid at great distances we may conclude that from infinity to 0.33 wavelength spacing between antennas which are substantially half the resonant linear conductor length, the phase angle between driving and reflector antenna currents is that calculable from the theory of the Hertzian doublet. Unfortunately, the onset of winter prevented measurements of ϕ at spacings

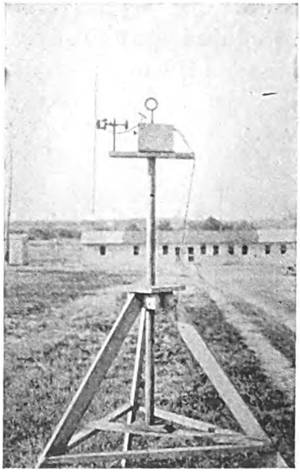

Fig. 12

less than 1/3 wavelength. As shown by Figs. 6 and 8 this is very nearly the optimum spacing between a driver and reflector antenna for maximum effect when both antennas are of equal length, and not 1/4 wavelength as has often been assumed. If Tatarinoff's $\pi/2$ value of ϕ for great distances is a lag, then his published curve will be the dotted one on Fig. 10. His angular maximum observation at 1/4 wavelength spacing (Fig. 10) is hard to explain.

The dependence of these results on the wavelength has not been determined. Theoretically no such dependence is to be expected for

[8] A 600-ohm carbon filament thermocouple was tapped across 1/6 of a turn of the tuning coil, and the thermocouple current read by means of a Weston Model 301 microammeter symmetrically mounted with respect to the antenna halves.

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systems the scale of which is proportional to the wavelength. The effect of the ground is also unknown, but it is not believed that it was dominant. The polar diagram of the generator without reflector was taken at a rather close range, and when the fixed radius brought the measuring antenna near to the direct-current power down leads a bad hump was noticed. By roughly determining the ratio of driving antenna current to down lead current it was found by computations that the probable error introduced, at the spacings actually used, was less than the errors of tuning and setting of θ. The angular range of the reflector antenna arm was 180 deg., and over this range the reflector antenna meter showed no change. The use of an anti-resonant central antenna tune should not introduce error as compared with the preferable series tune, the latter not so readily tapped for meter operation.

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Proceedings of the Institute of Radio Engineers
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THE PROPAGATION OF LOW POWER SHORT WAVES IN THE 1000-KILOMETER RANGE*

By
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Summary—*A description is given of a series of experiments carried out between two ground stations, and between an airplane and a ground station, to determine whether it is possible to obtain with relatively low power reliable short-wave communication over distances of 500 km, or more. Continuous-wave transmitters supplying a constant power of two watts were employed throughout the experiments. Results at fixed distances are recorded and discussed, particularly with regard to fading in summer and winter. An airplane installation, operating into a fixed dipole antenna is described, and the results of a large number of observations at ground receiving stations, of the signals received from the airplane in flight are presented.*

IN earlier communications,[1] the Division for Radio and Electrical Engineering of the German Experimental Institute for Aeronautics has already pointed out the advantages offered by the use of short waves for radio communication in aerial transportation, as compared with long waves which have been used exclusively up to the present. The first experiments showed immediately that the long ranges which could be covered by equipment of relatively small dimensions and weight constituted some of these advantages.

It is true that there were available a large number of investigations[2] regarding the propagation of short waves over very long distances. However, the distances to be considered in connection with present air traffic are those up to about 500 km and in exceptional cases up to 1000 km, which must be covered continuously by the radio equipment on board the aircraft. Systematic investigations of the wavelengths suitable for this purpose, and of the power of the transmitting stations required, have not been published hitherto.

* Dewey decimal classification: R113. Original manuscript received by the Institute, January 10, 1929. Translation received February 19, 1929. Communication of the "Deutsche Versuchsanstalt für Luftfahrt" (German Experimental Institute for Aeronautics, Berlin-Adlershof, Division for Radio and Electrical Engineering).

[1] H. Fassbender, K. Krüger and H. Plendl, *Naturwissenschaften*, **15**, 357, 1927. H. Plendl, *Zeits. f. tech. Physik*, **11**, 456, 1927. H. Fassbender, *Luftfahrtforschung*, **1**, 121, 1928. K. Krüger, H. Plendl, *Jahrb. d. drahtl. Tel.*, **31**, 169, 1928. Experiments with short waves during the trip of the airship *Graf Zeppelin* to America, *E. T. Z.*, **50**, 16, 1929.

[2] References to existing literature to be found in: A. Sacklowsky, *E. N. T.*, **4**, 62, 1927. R. Mesny, *Les Ondes Electriques Courtes*, Paris, 1927. R. Mesny, *L'Onde Electrique*, **76**, 129, 1928. L. W. Austin, PROC. I. R. E., **16**, 348; March, 1928.

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The Radio Division, under the supervision of Prof. Dr. H. Fassbender, therefore took upon itself the task of investigating these problems. Most important was the question whether it would be possible to cover the entire range of distances continuously with a single wavelength, or with a band of wavelengths of a certain width, without communication being impaired to any appreciable extent by the phenomenon of weakening zones.

Another problem was the determination of the influence of the power, and of the time of the day and the season, on the propagation of these waves.

Equipment

Table I lists the equipment used in the present experiments.

The Lorenz set, mentioned under No. 1 of the table, generates its high-frequency energy in a single quartz-controlled stage. The low limit of its wavelength is therefore about 40 m, as quartz crystals which are reliable in operation can be manufactured, with the means available at the present time, only for wavelengths down to this value. Signals are sent by the interruption of the anode voltage, so that the

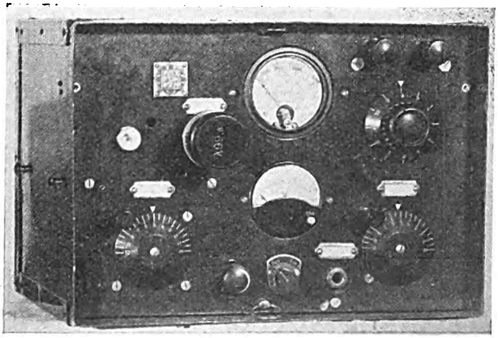

Fig. 1—Short-wave Transmitter for Airplanes. Design DVL—Telefunken (improved type).

oscillation of the quartz must start anew each time the key is pressed down. This system of signalling has two drawbacks: The impulse at starting under certain conditions will excite one of the secondary waves of the quartz which often appear in crystals of small size, instead of the primary wave; this causes a sudden change in the tone in the receiver, or even inaudibility. Furthermore, the slight change in frequency which may easily occur at the beginning of the oscillation is made evident at the receiving end in a disturbing manner as a change in tone, especially at high speed.

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TABLE I

LIST OF EQUIPMENT USED

No.	Designation of equipment	Manufacturer	Type of wiring	Range of wavelengths in meters	Antenna power of transmitter in watts	Weight without batteries in kg	Figure No.
1	One-knapsack set SERKT 127 Transmitter:	C. Lorenz A.-G.	quartz-controlled, one stage without intermediary circuit	40–60	2		
	Receiver:		audion, 2 low-frequency stages	30–60	—	5.7	
2	Short-wave transmitter for airplanes (first experimental type)	Telefunken G.m.b.H. in cooperation with Radio Division of DVL	(a) quartz-controlled, one stage with intermediary circuit	40–80	2	2.2	
			(b) quartz-controlled, two stages with duplication of frequency	20–40	2	4.5	
3	Short-wave transmitter for airplanes (improved type)	"	quartz-controlled, two stages with duplication of frequency	30–70	2	4.0	1 and 2
4	Laboratory transmitter	Radio Division of DVL	quartz-controlled, double duplication of frequency Amplification of capacity	10–60*	10 or 60	14.4	
5	Short-wave receiver for large stations, Gr. 98 special	Telefunken G.m.b.H.	push-pull audion, 3 low-frequency stages	11–80*	—	14.3	
6	Short-wave receiver for airplanes	"	audion, 3 low-frequency stages	30–70	—	5.0	3
7	Short-wave receiver for large stations, E.R.K.327	C. Lorenz A.G.	audion, 2 low-frequency stages	12–100*	—	12.1	
8	Rectifier measuring apparatus	Radio Division of DVL	grid rectification with measuring instrument in anode circuit	—	—	2.2	

* with interchangeable coils

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In order to eliminate these drawbacks, the 2-watt short-wave transmitter for airplanes, mentioned under No. 2 in Table I, was first developed. This set consists of two stages, according to wiring scheme *b* (Table I). The first stage is controlled by a quartz crystal and has a wavelength range from 40 to 80 m. In the second stage, the quartz frequency is doubled, the low limit of the wavelength being consequently reduced to 20 m. In this set signalling is done in the anode voltage (about 200 volt) of the frequency-doubling stage, the quartz-controlled stage being constantly in the condition of oscillation. The superposed tone produced in the receiver by such a transmitting set is perfectly pure and has a constant frequency; therefore it is easily distinguished from the disturbing noises and is very suitable for high speed telegraphing. This advantage would also be obtained if, in the keyed second stage, a power amplification of the quartz frequency were provided,

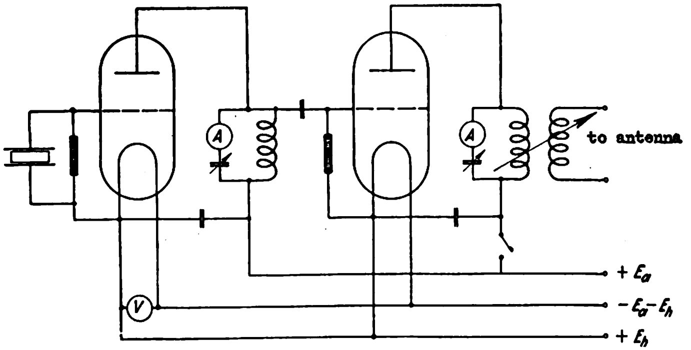

Fig. 2—Basic Wiring Diagram of Short-wave Transmitter for Airplanes, Quartz-Controlled Type with Duplication of Frequency. Design DVL—Telefunken.

instead of the doubling of the frequency. In this case, however, because of the amplifier circuits tuned to the quartz wave, the coupling would be too large between the antenna and the quartz stage that continues to oscillate during the intervals of the transmission, that is, when the key is released. When such a transmitter is being operated, the superposed tone in the receiver during the intervals consequently would not disappear, but only decrease in intensity. This, however, would impair the legibility of the signals.

The quartz-controlled first stage can also be used independently, but in this case the drawbacks referred to in the beginning of this article make themselves felt. The higher cost entailed in the elimination of these drawbacks by the addition of a doubling stage is in general well spent, for operation sets. Therefore, the quartz control and the

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doubling of the frequency were combined in a single cabinet, in the improved type of short-wave transmitter for airplanes (No. 3 in Table I). The range of wavelengths of the doubling stage is from 30 to 70 m. Fig. 1 shows a view of this apparatus and Fig. 2 the basic wiring diagram of the latter.

The reception in the airplane is made relatively difficult by the disturbances caused by the running motor, such as the noise of motor and propeller, vibrations and ignition sparks. A good short-wave receiver for airplanes must therefore have special requirements. With a minimum weight and space, it must give very strong amplification in order to be able to exceed in intensity the disturbing noises reaching the ear from the outside. Furthermore, it must be soundly built and protected against acoustic influences, in order to prevent the ever present mechanical and acoustic vibrations from exerting a disturbing influence on reception. Especially as regards the inevitable noise of

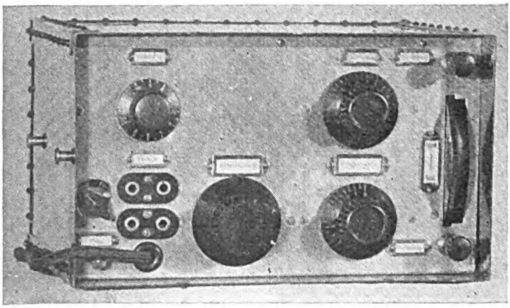

Fig. 3—Short-wave Receiver for Airplanes. Design DVL—Telefunken.

the ignition, it is important to obtain a pure constant tone in reception, which can be well distinguished from its background. If this condition be fulfilled, reception in a flying plane is still possible even when the intensity of the signals occasionally drops somewhat below the relatively high level of the disturbances.

For the major part of the reception observations made in the airplane, the receiver mentioned under No. 5 was used. The latter is a special form of the "Telefunken" receiver for large stations; it is different from the latter insofar as it was provided with a third low-frequency amplification stage, instead of the heterodyne, and instead of a copper cabinet, with a lighter one of aluminum. This receiver generally gave satisfactory results, but it did not produce a pure superposed tone due to the vibrations of the airplane. Passing through certain intermediate types, the development led to the short-wave

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receiver for airplanes mentioned in Table I under No. 6 and shown in Fig. 3. This receiver, while possessing the same sensitivity, represents a great improvement in weight and space; also, it is considerably less sensitive to vibrations.

The investigations discussed in the next chapter not only served the purpose of collecting data by observation concerning the phenomena of propagation but also that of developing and testing the apparatus described above.

Procedure of the Experiments and Results

In order to solve the problem stated above, it was necessary to sub-divide the experiments in the following manner.

For *constant distance*, the intensity of the signals in relation to the time of day was observed with different wavelengths as the parameter. Moreover, different airplane antennas were compared in this respect. The transmitter power was 2 watts in most cases.

The influence of *varying distance* on the intensity of the signals was investigated with different wavelengths as the parameter. In general, these observations were made exclusively in broad daylight throughout the whole distance. They were spread out over a whole year. The antennas used in these experiments were always horizontal dipoles.

(*a*). *Experiments with Constant Distance*

These experiments were made for the major part by two ground stations, one being situated in Berlin-Adlershof, the other one in Munich. The distance between these two stations was 500 km. Adlershof was generally the transmitting station, while the reception was observed in Munich. In order to keep the transmitting station in Adlershof continuously informed about the results of the reception, there had been installed in Munich, beside the receiver, a small 2-watt transmitting set which could, upon request, pass on the information at once. For the purpose of comparing airplane antennas, local flights over one of the two stations were made, while the other station observed the reception; in this way, the distance between transmitter and receiver remained practically constant.

The transmitters used during these experiments were installed in Adlershof in the main building of the Radio Division, whose equipment has been described in previous publications.[3] Insofar as Adlershof had to deal with observations of the reception, these were made in a small isolated reception building, in order to prevent disturbances. This small building was connected with the main building by means of

[3] See footnote 1 and also H. Fassbender, *Jahrb. d. drahtl. Tel.*, **30**, 173, 1927.

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a double conductor, so that the transmitters could also be operated from this observing station.

In Munich, the apparatus was also located in a special small building.[4] The antenna was here, in the same way as in Adlershof, a horizontal dipole with a length of about twice 8 m, and with bifilar conduction of energy.

The experiments between the two ground stations were primarily for the purpose of collecting data on the behavior of different wavelengths during different hours of the day. It was desired to ascertain if and by what means suitable communication during the daytime could be established over a distance of 500 km, with outputs of from

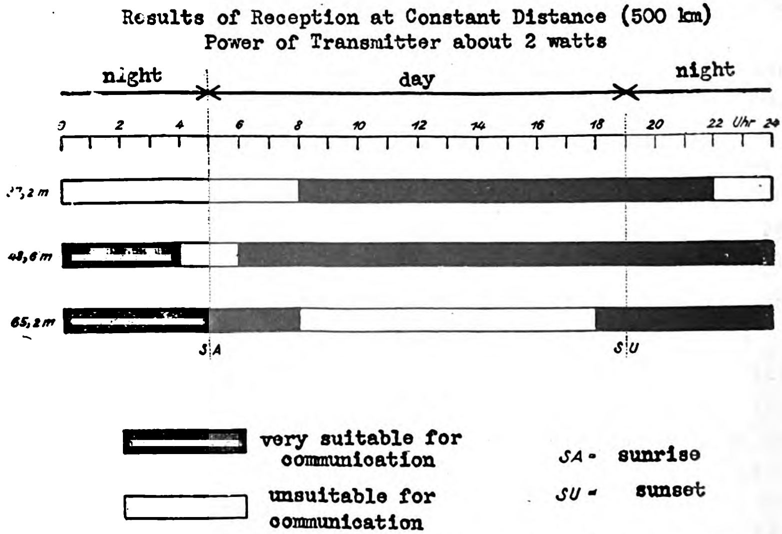

Fig. 4—Graphic Presentation of the Results Obtained with Reception at Constant Distance.

1 to 10 watts. The wavelengths used varied between 30 m and 65 m, the transmitters functioning exclusively with undamped telegraphy.

Fig. 4 shows part of the results of these experiments for the three wavelengths principally used, namely, 37.2 m, 48.6 m, and 65.2 m. The black portions of the bars indicate the hours during which it was possible to use these wavelengths for communication, whereas during the hours indicated by white portions of the bars, no communication, or only a very faint one, was obtained. The data represented here

[4] This small building was located on the premises of the "Electrotechnische Versuchswerkstätte G.m.b.H." (Workshops for electrical experiments) which also supplied the equipment required, such as anode storage batteries, heating batteries, etc.

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relate to the middle of April. They vary with the season, in connection with the change in the length of the day. The figure merely represents a diagrammatic condensation of a large number of experiments and does not claim to show quantitative values.

It is interesting to note that the limits of the fading and the reappearance of the short waves, as shown in the figure, are relatively very distinct.[5] The transition from a large volume of sound to near inaudibility generally takes place in a few minutes. At this time reception suddenly wavers greatly, that is, the frequency of fading increases many times, while the amplitude of the signal intensity decreases rapidly. In this critical period, the intensity of the reception fluctuates in the course of a few seconds, and sometimes in the course of fractions of seconds, in the ratio 1: 1000 and more.

Brief variations in the intensity also occur frequently at other hours, especially around noontime, but to a considerably lower degree, about 1:10 and more rarely 1:100 read on the measuring instrument. Because of the logarithmic sensitivity of the ear, variations in intensity in the ratio 1:10 have but little influence on the audibility. At other times, especially during the evening and night hours, the intensity of reception varied only within narrow limits, about 1:1.5 and in several cases even a perfect constancy of the signal intensity for several hours was observed on the rectifier measuring instrument.

An essential impairment of the reception by atmospheric disturbances could hardly be found during any of the observations, provided there were no indications of a thunderstorm in the immediate vicinity of the observing station. The intensity of the signals amounting to from 2 to 8 ma, and even to a maximum of 30 ma, was in general considerably above the level of atmospheric disturbances, the latter being seldom higher than 0.05 ma. On the other hand, temporary disturbances of local origin (commutator sparks, ignition sparks, etc.) were annoying, but could be eliminated to a large extent through proper selection of the location of the observing station.

A picture of the wave propagation phenomena can be obtained in the following manner.

The failures in reception occurring in some places during the night and in the early morning hours, for shorter waves (37.2 and 48.6 m in Fig. 4) are evidently caused by a shift in the minimum distance required for the return of the space wave to the surface of the earth, that is, by a displacement of the "skip distance" away from the sender, during the night. This phenomenon may be imagined as being caused by the fact that during the night the space wave due to the less in-

[5] See also R. A. Heising, Proc. I. R. E., 16, 75; January, 1928.

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tensive ionization of the lower layers, is refracted at a greater altitude than during the daytime. The diagram in Fig. 5[6] visualizes this phenomenon. The lower boundary of the Heaviside layer during the night gradually shifts upward from I to III, so that the innermost wave belonging to the skip distance shifts from *A* to *C*. At a certain moment, this limiting wave passes the location *B* of the receiver, the result being a rapid decrease in the intensity of the tone. In the morning, the process is reversed, the result being a correspondingly rapid increase in the intensity of the tone received at *B*. Therefore, it is not necessary to assume that the sudden variation in the intensity of the sound during fading and the reappearance of the wave is caused by a correspondingly rapid variation in the altitude of the Heaviside layer.

Contrary to the waves with a short length so far considered, for which the reception is suspended during the night or in the early morning hours, the moments when the somewhat longer waves fail (for example those of 65 m in Fig. 4) occur around noon. The transition

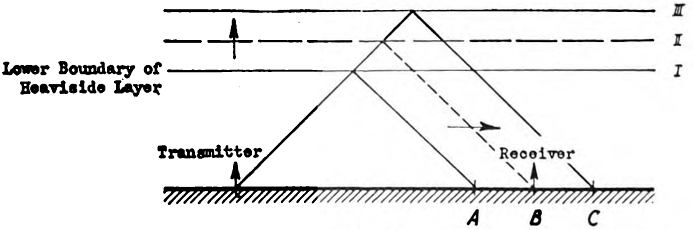

Fig. 5—Diagram of the Boundary Wave of the Fading Zone.

differs here from that occurring in the case of shorter waves, in that it is gradual. This difference must be ascribed to the fact that with increasing wavelength, the guided wave becomes active at points farther and farther away, while the innermost limit of the space waves shifts toward the sender, so that space wave and guided wave overlap. Therefore, fading zones, which were the cause of the sudden variation in tone intensity, as shown above, do not occur here any longer.

A similar result as obtained by the experiments described above between the two ground stations was also obtained by numerous local flights above Berlin-Adlershof and above Königsberg in East Prussia, these flights being made during different times of the day and also during the night. In this case, the transmission occurred with different waves from the airplane while the latter was in the air, and the reception was observed in Munich, the distance being about 500 and 1000

[6] For the sake of simplicity, simple reflection of the waves has been shown in the figure. Furthermore, it has been assumed, also in order to simplify the matter, that the critical angle does not vary perceptibly with the time of the day.

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km, respectively. It was proved by these experiments that the results obtained with experiments between the ground stations also applied to a great extent to communication between an airplane and the ground. Furthermore during the numerous ascents and landings there was no perceptible difference in reception where the plane transmitted from the ground or from the air. Also, there was not found to exist any essential difference caused by the altitude[7] at which the airplane was flying during its transmission.

Furthermore, during these local flights, comparisons were made between different kinds of transmission antennas. The dipole always used in other cases was compared with a one-wire trailing antenna which was excited in one quarter or three quarters of a wavelength respectively. It was shown that the tightly strung dipole was essentially superior as to constancy of frequency, that is purity of superposed tone in the receiver, to the trailing antenna whose position is never

Fig. 6—Airplane with Dipole for Short Waves.

entirely stable. With regard to the intensity of tone, the three-quarter wavelength trailing antenna was slightly superior to the dipole, while the one-quarter wavelength trailing antenna was considerably inferior.

(*b*) *Experiments with Varying Distance*

Whereas the previous chapter dealt mainly with investigation on the propagation of short waves as a function of the time of day, the experiments described below had for their purpose the determination of the influence of the distance between transmitter and receiver on the intensity of the tone in the receiver. Metal airplanes of the Junkers F-13 type were available for this purpose,[8] equipped with dipole

[7] A similar result was also found for long waves (900 m), see F. Eisner, H. Fassbender and G. Kurlbaum, *Jahrbuch der drahtlosen Telegraphie*, 1909, 31, 1928. It is true that this condition changes when there are mountain ranges within the distance over which transmission takes place, whose shadow may exert a considerable influence on the long-wave communication. With short-wave communication, however, interposed mountain ranges cannot cause any disturbance, as the space wave which is the most active one bridges these mountains independent of the altitude at which the airplane is flying.

[8] Experimental flights were also made in a Dornier-Wal airplane whose wings were covered with fabric.

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antennas and corresponding interior equipment. The outside view of an airplane of this kind is shown in Fig. 6, while a view of the interior with the newly developed short-wave transmission and receiving apparatus for airplanes is shown in Fig. 7.

Numerous overland flights in different directions were made with these airplanes within the German frontiers and transmission from the airplane occurred mainly with undamped waves and a power of 2 watts. The observation of the reception was always taken care of in Adlershof, and often at the same time in Munich. As Adlershof was the starting and finishing point for all flights, the longest distance within Germany was limited to about 600 km when the reception was observed in Berlin. In order to be able to extend the experiments to

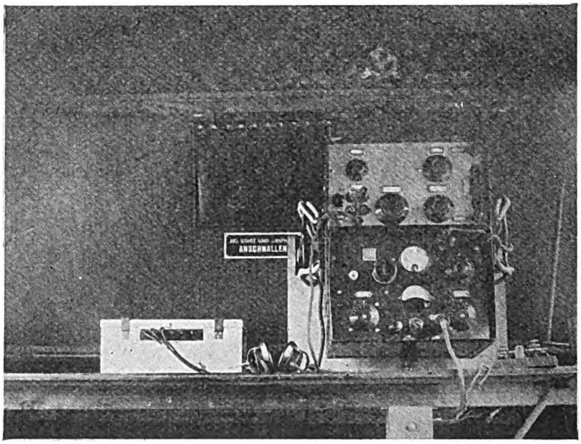

Fig. 7—Short-Wave Equipment in Airplane.

longer distances, without having the planes go outside the frontiers of Germany, several flights were made to Königsberg and Tilsit, in which cases the reception could be observed in Munich for a maximum distance of more than 1000 km. In addition to the 2-watt transmitter, a receiver was always taken on the flights, this receiver serving both for checking the transmission and for communicating with the two observing stations. During each of these overland flights, the transmitter on the airplane was kept in continuous operation. The key was operated automatically by means of a signal transmitter driven by clockwork. In addition to this, reports were transmitted on the position of the airplane and on the weather.

Fig. 8 shows the results of the observations in relation to distance, the receiver always being placed at a distance *O*, while the airplane

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TABLE II
LIST OF OVERLAND FLIGHTS

Serial No.	Date	Time of Day	λ Meters	Distance Covered by Flight	Observing Station
1	June 2, 1928	12:00–13:30	27.6	Königsberg—Danzig	München
	June 6, 1928	11:15–17:45	27.6	Danzig—Adlershof	"
2	June 2, 1928	12:00–13:30	27.6	Königsberg—Danzig	Adlershof
	June 6, 1928	11:15–17:45	27.6	Danzig—Königsberg	"
3	April 25, 1928	9:00–14:30	32.6	Adlershof—München	Adlershof
4	April 25, 1928	9:00–14:30	32.6	" "	München
5	April 27, 1928	9:00–14:45	32.6	München—Adlershof	"
6	April 27, 1928	9:00–14:45	32.6	" "	Adlershof
7	June 1, 1928	10:15–18:30	32.6	Adlershof—Königsberg	"
8	June 1, 1928	10:15–18:30	32.6	" "	München
9	March 19, 1928	9:00–15:00	37.2	Adlershof—Königsberg	Adlershof
10	March 19, 1928	9:00–15:00	32.6	" "	München
11	March 23, 1928	9:15–21:45	32.6	Königsberg—Tempelhof	"
12	March 23, 1928	9:15–21:45	32.6	" "	Adlershof
13	July 11, 1928	9:30–17:30	32.6	Adlershof—Friedrichshafen	"
14	July 13, 1928	9:30–12:30	32.6	Fürth—Adlershof	"
15	September 28, 1927	13:15–16:45	40.0	Norderney—Adlershof	Adlershof
16	February 18, 1928	11:15–12:30	40.0	Hamburg—Adlershof	"
17	February 27, 1928	13:00–17:00	40.0	Adlershof—Danzig	"
	February 28, 1928	10:15–13:15	40.0	Danzig—Tilsit	"
18	February 27, 1928	13:00–17:00	40.0	Adlershof—Danzig	München
	February 28, 1928	10:15–13:15	40.0	Danzig—Tilsit	"
19	March 6, 1928	10:00–15:00	40.0	Adlershof—München	Adlershof
20	March 6, 1928	10:00–15:00	40.0	Adlershof—München	München
21	March 8, 1928	12:00–15:45	40.0	München—Schkeuditz	"
22	March 8, 1928	12:00–15:45	40.0	" "	Adlershof
	March 9, 1928	9:30–11:00	40.0	Schkeuditz—Adlershof	"
23	July 26, 1928	9:30–17:15	40.0	Adlershof—Köln	"
24	June 27, 1928	9:45–13:15	40.0	Köln—Adlershof	"
25	July 18, 1928	8:30–12:30	41.6	Adlershof—München	Adlershof
26	July 19, 1928	10:00–14:30	41.6	München—Adlershof	"
27	July 31, 1928	9:30–16:00	41.6	Adlershof—Köln	"
28	August 1, 1928	10:00–13:45	41.6	Köln—Adlershof	"
29	August 24, 1927	13:30–14:45	46.3	Adlershof—Leipzig	Adlershof
30	August 24, 1927	14:45–15:45	46.3	Leipzig—Adlershof	"
31	August 29, 1927,	10:00–12:30	46.3	Adlershof—Hannover	"
32	August 29, 1927	15:15–17:00	46.3	Hannover—Adlershof	"
33	August 31, 1927	9:30–14:15	46.3	Adlershof—Köln	"
34	September 1, 1927	11:30–18:15	46.3	Köln—Adlershof	"
35	September 7, 1927	11:00–15:30	46.3	Adlershof—München	"
36	September 9, 1927	13:45–18:30	46.3	München—Adlershof	"
37	October 13, 1927	10:45–17:15	46.3	Essen—Adlershof	Airplane between Stolp and Adlershof
38	October 13, 1927	10:45–17:15	46.3	" "	
39	February 16, 1928	10:15–13:30	46.3	Adlershof—Hamburg	
40	October 7, 1927	11:00–13:30	49.8	Adlershof—Hannover	Adlershof
41	October 7, 1927	15:45–17:45	49.8	Hannover—Adlershof	"
42	October 12, 1927	12:00–17:30	49.8	Adlershof—Essen	Airplane between Stolp and Königsberg
43	October 12, 1927	12:00–17:30	49.8	" "	
44	August 3, 1928	10:15–14:30	49.8	Adlershof—Königsberg	Adlershof
45	August 4, 1928	7:00–11:15	49.8	Königsberg—Adlershof	"
46	August 6, 1928	11:00–17:00	49.8	Adlershof—Friedrichshafen	"
47	September 5, 1928	10:00–16:00	49.8	Friedrichshafen—Adlershof	"
48	October 2, 1928	9:15–17:30	49.8	Adlershof—Fehmarn	"
49	October 3, 1928	10:00–15:15	49.8	Fehmarn—Adlershof	"
50	August 8, 1928	9:15–15:00	52.7	Friedrichshafen—Adlershof	Adlershof
51	September 4, 1928	7:15–13:45	52.7	Adlershof—Friedrichshafen	"
52	March 1, 1928	10:15–15:00	55.2	Königsberg—Adlershof	München
53	March 1, 1928	10:15–15:00	55.2	Königsberg—Adlershof	Adlershof

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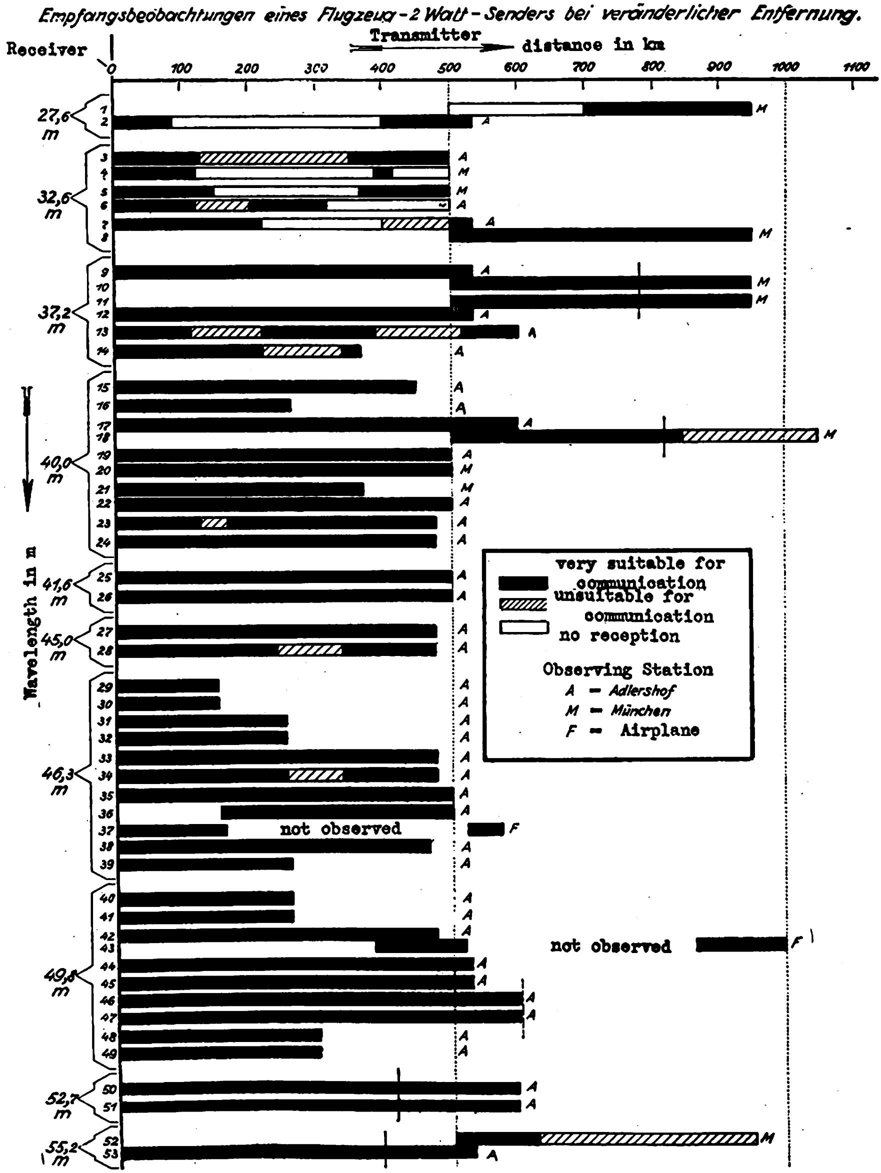

Fig. 8—Results of Reception of Signals from a 2-watt Transmitter in Airplane, for Varying Distance.

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transmitter must be considered as moving in the direction of the abscissa. Each observation of an overland flight corresponds to a horizontal bar, the bars indicated by *A* having been plotted in Adlershof, those indicated by *M* in Munich. The bars are numbered continuously and arranged according to the wavelength. The black portions in the diagrams correspond to reception very suitable for communication; the cross-hatched portions indicate wavering uncertain reception and the white portions represent the range of distances where reception fails. Further data concerning the individual flights, such as date, time of the day, and course, are given in Table II.

A review of the diagrams shown in Fig. 8 shows clearly the essential difference between the shorter and the longer waves within the range of 27 to 55 m. The shorter waves, below about 38 m, show distinct fading zones, whereas they come over in a satisfactory manner over longer distances. For wavelengths between about 40 m and 46 m, the fading zones occur only exceptionally, so that the chance of good communication increases for the shorter distances. For longer waves, with a length of 50 m and over, no fading zones are perceptible any longer. This wave band (around 50 m) therefore proved to be suitable for constant communication over a range of distances up to about 600 km.

This favorable result obtained with the 50-m band was confirmed by a number of overland flights not mentioned in Fig. 8, during which the signal intensity of a transmitter located on the ground was observed by means of a receiver on the airplane. This transmitter operated, in the majority of the cases, with undamped waves of 48.5 m, or with waves having a length close to this, and with an antenna power of about 60 watts. Four of these flights extended over a distance of 600 km, and an equal number over a distance of 300 to 450 km. In these cases, a satisfactory signal intensity, without fading zones, could be observed with receivers of sufficient sensitivity (audion and 3 A.F.)

According to Fig. 8, the fading zones for the waves of 27 m and 32 m occur between about 100 and 400 km. The two boundaries of these zones have an entirely different behavior. Whereas for the inner boundary the reception grows weaker in a gradual manner, there occurs in the case of the outer boundary an abrupt change in the tone intensity corresponding to the sudden action of the space wave. There is not always a complete extinction of the reception in the fading zone; rather it happens that the transmitter, even with such a low power as 2 watts, remains faintly audible all the time. In principle, it is impossible to indicate definite boundaries for these zones, as shown by the example of observation No. 6 in Fig. 8. In fact, in the middle of the

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range which had appeared to be, in all other observations of this wave band, a pronounced fading zone, there was obtained good communication over a long distance (about 120 km).

It must be assumed that the zones of strong weakening or entire lack of reception observed for a transmitting power of 2 watts would no longer have any disturbing effect if the power were sufficiently increased, in the ratio of about 1:1000 to 1:10000; this assumption is based on experience previously gathered[4] with high powers (8 kw). The experiments made at the time with high powers showed that even with considerably shorter wavelengths (15, 18, and 28 m), there cannot be found any absolutely dead zones, this being in contrast with the results obtained by Reinartz, Taylor-Hulburt, and Heising.[9] The only result was that zones of strong weakening of the reception intensity were observed, this being in accordance with the investigations of T. L. Eckersley,[10] published at about the same time, which, in addition to similar results obtained by observations, contain a theoretical explanation of these phenomena.

For the wave with the next greater length of 37 m, the results of the observations were very inconsistent. Whereas in the cases 9 and 12 the reception was always free from weakening, cases 13 and 14 showed spots where the reception was uncertain. The discrepancy may have been caused by the difference in seasons, as the former observations were made at the end of March, the latter in the beginning of July.

In the adjacent wave band of 40 to 46 m, about twenty observed flights gave weakening zones in only three cases, the longest distance being 90 km. In this connection, it must be observed that both at the transmitting and the receiving end, exclusive use was made of horizontal dipoles. More recent experiments, however, seem to indicate that the weakening zones mentioned above would not be so pronounced if vertical antennas or a combination of different kinds of antennas were used at the receiving end.

With the exception of these three cases where weakening zones were observed, these waves and especially the 50-m wave continuously gave a large volume of tone at the reception end resulting generally in a pure loud speaker reception. It was always possible to obtain distinct

[9] Reinartz, *QST*, **9**, 9, 1925. A. H. Taylor, Proc. I. R. E., **13**, 677; December, 1925. A. H. Taylor and E. O. Hulburt, *QST*, **1**, 13, 1925. A. H. Taylor and E. O. Hulburt, *Phys. Rev.*, **27**, 189, 1926. E. O. Hulburt, *Jnl.* Franklin Institute, **201**, 597, 1926. R. A. Heising, J. C. Schelleng, and G. C. Southworth, Proc. I. R. E., **14**, 613; October, 1926.

[10] T. L. Eckersley, *Jour.* I. E. E., **65**, 600–644, 1927; compare also A. H. Taylor, Proc. I. R. E., **15**, 707; August, 1927.

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and easily measurable deflections of the rectifier measuring instrument after the two low-frequency amplifying stages of the receiver.

The average course of events with regard to the signal intensity observed was about as follows. When the airplane, equipped with the transmitter, moved away from the observing station, the signal intensity decreased in the first 20 km from about 15 ma to 5 ma; thereafter it remained at this amount during the entire remaining part of the flight up to a certain critical distance. With the tubes used in the measuring apparatus, this deflection corresponded to a great volume in the loud speaker reception, without being impaired by the outside disturbances. When this distance was exceeded, the signal intensity decreased rapidly, but it always remained sufficient for reception by means of a head set. This critical distance has been indicated in Fig. 8 by a vertical line. It was found to lie, for the 37 and the 40-m waves, at about 800 km; for the 53 and 55-m waves, at about 400 km; and for the 50-m wave, at about 600 km. The critical distance therefore increases with decreasing wavelength. The width of these critical zones was about 10 to 20 km and was covered by the airplane in a few minutes. Both the sudden decrease in signal intensity with increasing distance, and the equally sudden increase in signal intensity with decreasing distance, were repeatedly observed. In the case of observations 10 and 11 in Fig. 8, for example, the same critical distance (780 km) for the wave with a length of 37.2 m was observed both during the outward flight and the return flight.

The fading phenomena observed during transmission from the airplane in flight were of the same order of magnitude as those observed for a constant distance, under normal circumstances. Within the critical distance, for which the signal intensity was high and practically constant, it was never found that the communication was impaired by possibly existing fading phenomena. Only in the case where this distance was exceeded, the effect of fading occasionally caused a disturbance during a short period of time. The critical distance therefore constitutes the maximum range for communication by means of the wave under consideration, for which continuous good reception is certain ("maximum distance for good communication").

The observations made in the manner described above appeared to be independent of the altitude of the flight. The signal intensity remained unchanged whether the airplane transmitted during the flight or, over the same distance, from the ground. In several cases reception was still possible when the airplane, at a distance of 500 km from the observing station, was located, together with its transmission apparatus, in a closed shed reinforced with steel.

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In addition to the experiments described above, during which the transmitter was located in the airplane, there was also made a series of observations on reception on the airplane. These experiments were intended primarily for the development of a short-wave receiver for airplanes, and also for determining the power of a transmitter located on the ground in order to communicate with airplanes. The wave band of from 46 to 50 m, which had been proven to be suitable in the above investigations, was mainly used in this connection. The experience was collected during ten long distance overland flights, the longest distances lying between 300 and 600 km.

When the airplane is on the ground, with its motor stopped, the results of the observations mentioned above also apply, without further complication, to the reception inside the cabin. When the motor is running, however, we have to deal with the disturbances already mentioned, which impair the clarity and relative signal intensity of the reception. Because of these disturbances, the 2-watt transmitter usually will no longer be sufficient in this case: at any rate, the transmitters on the ground which are intended for communication with airplanes will be given much higher powers. However, it has been possible repeatedly to get continuous reception in the airplane, with satisfactory signal intensity, up to a distance of 450 km, by means of the receiver described under No. 5 in Table I, a transmitter with a power of 2 watts on the ground, and undamped telegraphy. In the other cases, the transmission from the ground station occurred with about 60 watts, the reception giving good signal intensity up to a flight distance of 600 km.

The results thus far obtained with observations of the reception on board the airplane in flight show that the favorable results with waves around 50 m in length, obtained in the experiments discussed above, also apply to this case. These observations have not yet been concluded, however. They rather require further clarification of the question of the power of the transmitter on the ground, sufficient to insure dependable communication.

An important point to be considered during the further investigations is the elimination of the fading phenomena. This elimination has for its purpose the improvement of short-wave communication by the establishment of an even signal intensity which remains constant during a long period of time. The solution of this problem must be sought primarily in the selection of the proper kind of antennas to be used in the ground station.

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Proceedings of the Institute of Radio Engineers
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FURTHER NOTE ON THE IONIZATION IN THE UPPER ATMOSPHERE*

By
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A RECENT paper[1] by the present writer has brought from other workers in the field a considerable amount of discussion through the medium of personal letters. The author believes that the objections which were in this way raised have been shown not to be valid and that his correspondents now agree in this statement. However, it may be well to put on record certain considerations the omission of which for the sake of brevity caused difficulty.

It was proved that the apparent height found by the "fringe" method employed by Appleton and Barnett, Bown, Martin, and Potter, and by Heising is the same as the apparent height found by the method of Breit and Tuve[2]. In the course of this proof, the following expression for group time was used.

$$T_g = \frac{d}{df}(fT_p), \tag{1}$$

in which f is the frequency and T_p the phase time. This expression was used instead of the usual one involving phase and group velocities in order to avoid the difficulty brought about by the fact that different frequency components follow different paths. No difficulty is encountered in homogeneous media. Letting S be the distance and U and V the group and phase velocities we have:

$$T_g = \frac{S}{U} = S\frac{d}{df}\left(\frac{f}{V}\right) = \frac{d}{df}\left(\frac{fs}{V}\right) = \frac{d}{df}(fT_p)$$

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, May 18, 1929.

[1] J. C. Schelleng, "Note on the Determination of the Ionization in the Upper Atmosphere," Proc. **16**, 1471; November, 1928.

[2] Since the writing of the paper under discussion, attention has been called to the fact that E. V. Appleton at the Brussels meeting of the U. R. S. I. presented a proof of the equivalence of these methods based on the method of rays and Fermat's principle. The proof given by the writer does not involve the method of rays and Fermat's principle is not needed. Appleton's paper was given on September 13, 1928.

In these methods, the apparent height is *defined* as the altitude of the isoceles triangle whose base is the line between stations and whose sides are of a length such that if the atmospheric wave is assumed to travel along them the observed "fringes" and the observed group delay will be the same as that observed. An essential part of this definition is the assumption that the path is independent of frequency, i.e., $dD/df = o$, where D is the difference between the length of the paths of the atmospheric and ground waves. It is well-known that the path is really dependent on frequency, but this is no objection as long as we are defining an *apparent* height.

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Now without further analysis it is obvious that even in the case of non-homogeneous media, in which therefore the rays of different frequencies which make up a pulse follow different paths, this expression is still true. The group arrives at the receiver when certain phase relations are established between the components. It is true that T_p is a function of the method of wave propagation involved, but having given T_p we need not know the mechanism of propagation. The expression given above still applies.

Perhaps, however, a more formal proof will be preferred by some. Let two sinusoidal waves pass from point A to point B by any path and by virtue of any mechanism whatever.

Letting $n=2\pi f$, we may represent the first wave at point A as $\sin n_1 t$ and the second as $\sin (n_2 t-\phi)$. The difference of phase is therefore

$$[(n_1-n_2)t+\phi] \tag{2}$$

At the same time t, the phase at B is less depending upon the time of phase propagation, or the time required for a crest to travel from A to B. The two waves at B and at time t are therefore $\sin n_1(t-T_{p_1})$ and $\sin [n_2(t-T_{p_2})-\phi]$. The difference of phase at B is therefore

$$[n_1(t-T_{p1})-n_2(t-T_{p2})+\phi]. \tag{3}$$

Now the time required for the group to travel from A to B is T_g. It is a time such that the phase differences at B at time $(t+T_g)$, are the same as they were at A at time t. This is true because these phase differences determine how the waves interfere to produce the envelope of the group. Substituting $(t+T_g)$ for t in (3) and equating to 2, we have $[(n_1-n_2)t+\phi]=n_1(t+T_g-T_{p_1})-n_2(t+T_g-T_{p_2})+\phi$. As a result we obtain

$$T_g=\frac{n_1T_{p_1}-n_2T_{p2}}{n_1-n_2}. \tag{4}$$

This expression may be used for the case of any two frequencies. In the case of narrow clusters such as those with which we are usually concerned, it is more convenient to use differential notation

$$T_g=\frac{d(nT_p)}{dn}=\frac{d(fT_p)}{df}. \tag{5}$$

This is seen to be identical with (1). It will therefore be seen by reference to the original paper that the fringe experiment and the group experiment give identical results, the identity being proved regardless of what the mechanism will eventually prove to be. The proof is more general than one based on ray theory, and attention

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is particularly called to the fact that Fermat's principle of least time is not needed to prove the equivalence of the two methods.

With reference to the third method of determining the "height" of the layer, i. e., the triangulation method, Breit and Tuve showed that neglecting dissipation and the effect of the earth's magnetic field, it gives the same result as the echo experiment. However, they assumed that the group time is given by the expression $\int ds/U$, U being the usual function of the ionic concentration at points on the ray path of one of the frequencies of the cluster. This expression is correct, but it probably is not obvious in view of the fact that the ray paths of the component frequencies of the cluster differ from each other.

In special cases of ionic distribution we may calculate the group time by use of (1). The procedure is to calculate the phase time by standard methods, remembering that in transmission between two points the initial earth angle is a function of frequency while the distance is not. About a year ago the writer carried out this procedure in the case of a linear increase in ionic concentration with height. The result was that the method of Breit and Tuve was checked. It was then realized that the explanation is to be found in the well known fact that the ray path in general is one of least time.[3] While the different rays of the cluster follow slightly different paths, an error of only a second order is incurred by assuming that ray $(f+\Delta f)$ actually follows the path of ray f.

The error is of a second rather than of a first order because while a slight upward shift of the path would result in a first order increase in the distance to be travelled, it would also be accompanied by a first order increase in average phase velocity due to the greater ionization. The phase time is therefore not changed. This balance of course applies only to the vicinity of the actual ray path. Since by least time considerations we see that no error in T_p or in $f\ T_p$ is introduced by considering that the components travel over the same path, we need not consider ds to be a functionof frequency. We may therefore write:

$$T_g = \frac{d}{df}(fT_p) = \frac{d}{df}\left(f \int_A^B \frac{ds}{V}\right) = \frac{d}{df}\int_A^B \frac{f}{V} ds$$

$$= \int_A^B \frac{d}{df}\left(\frac{f}{V}\right) ds = \int_A^B \frac{ds}{U}$$

Therefore the group time is the same as though the rays travelled over the same path, and the method of Breit and Tuve is correct.

[3] E. V. Appleton independently arrives at this conclusion in the U. R. S. I. paper. The present proof is essentially the same, but emphasis is here placed on the physical aspects of matter.

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AN ELECTROMAGNETIC MONOCHORD FOR THE MEASUREMENT OF AUDIO FREQUENCIES*

By
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Summary—*The desirable properties for an instrument for measuring frequencies over the audible range are briefly mentioned and a suggested electrically excited monochord is considered. In practice certain difficulties are found and lead to a proposal for employing the harmonic modes of vibration of the stretched wire. The theory of this is given, as well as the relation between the frequency response and the position of a movable bridge. The constructional details and the method of calibration from a single tuning fork are described in turn. Miscellaneous considerations concerning the practical operation conclude the paper.*

1. Frequency Measuring Methods

In a laboratory in which telephony research is undertaken it is essential that there should be some method of rapidly measuring the frequency of any current produced, and of setting a source of current to a given frequency.

An instrument for this purpose should have a range from 32 up to 5,000 cycles at least.

One method is to use an electrically excited tuning fork and obtain harmonics from this. But the labor and patience required to count up to, say, the thirtieth harmonic without error (only 480 cycles in the case of a 16-cycle fork) is such that the method can usually be used only as a check, and one has to rely otherwise on the calibration of the oscillator in use, which is not always too certain.

Another alternative is a large number of separate forks to cover the range. This is very expensive, and does not cover the gamut of frequencies continuously.

The author was faced with this problem and noting a brief reference[1] to the electromagnetic monochord decided to investigate its possibilities.

This monochord was a stretched steel wire carrying the current to be measured. The wire passed between the poles of a magnet, and by electromagnetic action is thrown into vibration when its natural frequency corresponds to the frequency of the current flowing through it. A bridge sliding along the wire adjusts the length in use, and therefore the natural frequency. From known data the position of the bridge corresponding to any frequency is found.

* Dewey decimal classification: R210. Original manuscript received by the Institute, January 10, 1929.

[1] P. K. Turner, *Jour.* I. E. E. (Wireless Sec.) 2, No. 6, p. 205.

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The writer, however, experienced considerable difficulty in practice. It was not easy to set the bridge accurately enough, at the higher frequencies especially; and at this part of the range the wire in use became so short that it refused to respond to the electrical excitation. Also the exciting system given did not work, and better results were obtained with an old Brown loud speaker magnet arranged to pull direct on to the wire.

The trial of thinner gauges of steel wire, down to the sizes employed for banjos, was unsuccessful on raising the natural frequency of the wire (in order to lengthen the upper frequency lengths, compared with their diameter, to get a better response) as the tensile strength decreased far more rapidly, with decrease of diameter, than the frequency went up.

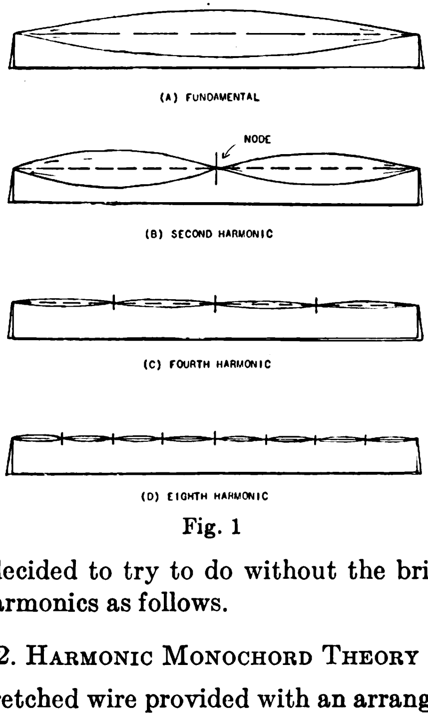

Fig. 1

It was then decided to try to do without the bridge and to work on a system of harmonics as follows.

2. Harmonic Monochord Theory

Consider a stretched wire provided with an arrangement to vibrate it at any frequency f upwards from its own natural period f_1. Now when $f=f_1$, i.e., when the exciting frequency is the same as the natural frequency, the wire will vibrate as a whole as in Fig. 1 (a). The nodes, or positions of no vibration, are at the ends of the wire, and the anti-node, or position of maximum amplitude of vibration, is at the center of the wire as shown.

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Now let $f=2f_1$, i.e., the second harmonic of the wire is excited. For convenience the fundamental will be considered as the first harmonic, as this agrees with the frequency ratios. Now we have one node in the center of the wire. Fig. 1(b).

Similarly (Figs. 1(c) and 1(d)) we may show that if n is the number of nodes in the wire then it is vibrating to a frequency $(n+1)$ times its fundamental f_1.

Further, if we know any harmonic frequency of the wire and the number of its nodes, we can find any other response frequency from the relation

$$f=f_1(n+1) \tag{1}$$

where f is the harmonic frequency.

By this means we may find the frequency of each harmonic response of the monochord as we raise the exciting frequency from f_1 upwards. The nodes are easily counted by running a finger nail or a piece of metal up the wire, and counting the times the harmonic becomes audible (as the indicator passes a node and does not interfere with the vibration).

A specimen calibration table is shown for the monochord about to be described. The harmonic points given were found sufficient for all ordinary purposes.

CALIBRATION TABLE

1/16 in. diam., 5 ft. wire		1/32 in. diam., 16 in. wire	
Harmonic	Frequency	Harmonic	Frequency
Fundamental	32.625	Fundamental	261
2	65.25	2	522
3	97.875	3	783
4	130.5	4	1044
5	163.125	6	1566
6	195.750	7	1827
8	261	8	2088
		9	2349
		10	2610
		11	2871
		12	3132
		13	3393
		15	3915
		18	4698

3. The Use of the Bridge

In general a series of points obtained from one standard tuning fork in this manner is sufficient, but there is also the method of obtaining a measurement of any frequency within the range by feeding it to the exciting magnet and sliding the bridge until resonance is found. The frequency range, however, is not so high as in the case of the harmonic method, for reasons already stated, though a special

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design of exciting magnets and the like would probably help here. The author has not had need to investigate this further up to the time of writing.

If l_1 is the length of the wire from end to end, and l_{11} is the electrically excited length stopped off by the bridge, then it can be easily seen that the relationship between the natural frequency f of the short length l_{11} and that of l_1 is

$$f/f_1 = l_1/l_{11} \quad (2)$$

By direct measurement f can always be determined; or a graduated scale may be fitted, though the writer has not found this latter worth while, as the harmonic points are generally amply sufficient, and a scale near enough to the wire for accuracy tends to foul the other parts.

The resonance is very sharp and, though the author has no exact data at hand, he believes that the accuracy of the harmonic method is at least comparable with other substandards. The advantage of the ease of checking and setting the frequency adjustments is obvious.

If the bridge is employed, however, the precision of adjustment depends on the mechanical design, and may not be high enough for certain work.

4. Constructional Details of Monochord Base

It is essential that the body of the monochord should be extremely massive as the strain imposed is immense. The author has not tried metal, but can recommend a 2×2 in. section length of wood, with two 4×1 in. boards bolted flat on top and bottom. 3/8-in. steel bolts are good. The wood should be teak, or of a similar hard nature, though actually quite excellent results were obtained with oak boards and a deal center.

For the ends of the wire, piano pins (easily obtained from any piano shop) were employed. They were screwed tightly into 1/4-in. holes in blocks of hard wood at each end of the base. Slight counter-sinking of the top of the holes and the use of French chalk will facilitate the operation. A piano tuner's key will turn these pins and so adjust the tension of the wire.

Instead of the pins a very stout worm drive mechanism would undoubtedly give finer adjustment.

The ends of the wires must not run direct to the fastening off pins, or buzzing and uncertain lengths of vibration will give trouble. It is most important to pass them through a clamp of two layers of ebonite fixed to the base with grooves to bite the wire tightly and positively in order to give an exact end to the vibrating chord.

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Further details of the base may be gauged from Fig. 2.

5. Wires and Exciting Mechanism

A piano wire about 1/16 in. in diameter and about 5 ft. long will go down to 32 cycles nicely and right up to the harmonics. It is very tedious to count about a hundred odd nodes for each high note check; therefore the writer employs this wire for up to about 261 cycles (roughly the 8th harmonic) and a short length of about 16 in. with a fundamental of 261 cycles (middle *C* philharmonic) for up to about 5000 cycles. There seems no reason to doubt that the harmonic response goes still higher than this, but the author's oscillator does not work beyond this point, consequently no actual tests have been made. The short wire is about 1/32 in. in diameter.

These sizes are the result of much experiment and appear to be the best.

Unless the very lowest frequencies only are needed the wires must have a mechanical tensioning device. Weights of practicable

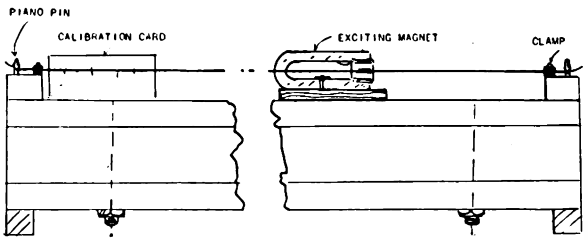

Fig. 2

size are useless for this purpose.

The amplitude of movement of the wires is very small—quite invisible—at the notes over, say 2000 cycles, and may reach as much as a half inch at 32 cycles. Hence the distance between the exciting magnet and the wire must be adjustable.

A convenient method is to mount the magnet on a heavy base at the side of the wire and move it to and from it, as required.

6. Calibration

This is easily performed by tuning the oscillator in use to any available electrically excited tuning fork, switching over to the monochord and adjusting the tension of the wire until the maximum response is attained. If the fork has a frequency which corresponds to a harmonic instead of the fundamental of the wire it is inadvisable to stop the latter with the bridge, as this will usually produce an error due to slightly

inaccurate measurement. Instead, work to the harmonic directly by means of counting the nodes.

The position of the nodes and their frequencies may be marked on the monochord. It is only necessary to mark, say, the left-most, if this is the end of the wire used for high frequencies with the bridge. For the top notes a piece of card close behind the wire is necessary to avoid errors in reading due to the crowding of the nodes at this part of the frequency range.

In practice any setting may be found in a few seconds once the monochord is calibrated.

7. Miscellaneous

A middle *C* tuning fork (philharmonic 261 cycles) may be excited by mounting it with an old earphone magnet system. Care should be taken that the correct note response is employed, and not a harmonic, as the fundamental will not usually be by any means the loudest reponse of the fork when used in this way.

To render the harmonics easily found, particularly when first calibrating the monochord, plenty of power to the exciting magnet should be employed. If the a-c source is not powerful enough an extra valve amplifier should be interposed between it and the monochord. This method has the advantage also that no appreciable power need be taken from the source of current.

The author employs two LS5A valves (in push-pull to avoid saturation of the output transformer core) with 200 volts on the anodes. The monochord will work with much less than the full output of this combination.

The sharpness of the resonance of the wires is very great indeed, and failure to find harmonics is generally due to this cause. To avoid interference it is well to damp the unused portion of the wire when using the sliding bridge.

If difficulty is found in hearing the response of the wire, a telephone magnet system placed close up to it, as if to excite it, but with a pair of phones connected (if desired via an amplifier) to the coils of the magnet, will act as an excellent microphone. It will pick up only the movement of the steel wire it is close to, which may be an advantage in a busy laboratory.

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AN EMPIRICAL EQUATION FOR DETERMINING THE d^2i_g/de_g^2 OF DETECTORS*

By
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Summary—*An empirical equation for the grid-current grid-voltage curve of the C-327 tube is developed. By obtaining the derivatives of this equation rather than determining them from the i_g-e_g curve by graphical means the inaccuracy of the graphical methods is avoided. The equation holds accurately in the range of e_g encountered in practice.*

IN the March, 1929, issue of the PROCEEDINGS, an experimental method of determining the second derivative of the grid-current grid-voltage curve of electron tubes was presented by J. R. Nelson. The main advantage of the method lies in the fact that the great difficulty of evaluating the slopes at various points of the di_g/de_g curve by graphical methods is avoided. However, the method requires a know-

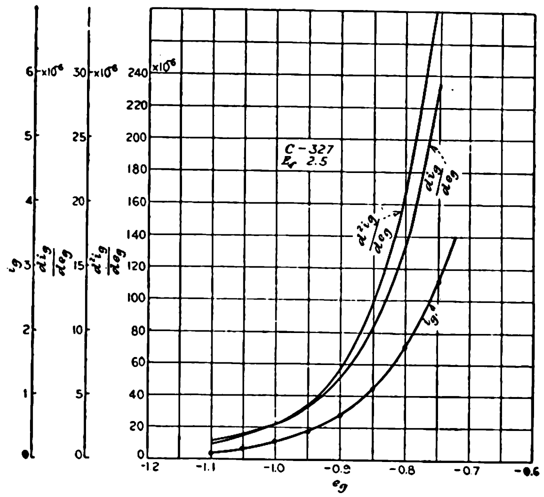

Fig. 1

ledge of the values of the first derivative, which are usually obtained from the grid-current grid-voltage curve by graphical means, and which are subject to the same inaccuracies which the method seeks to avoid in passing to the second derivative. It is clear, then, that

* Dewey decimal classification: R134. Original manuscript received by the Institute, March 25, 1929. Revised manuscript received May 28, 1929.

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the method is of value only insofar as the values of di_g/de_g, or r_g, are accurately known.

It is much more accurate, and quite simple, to obtain an empirical equation for the i_g-e_g curve; this can then be differentiated in order to obtain the first and second derivatives. In order to illustrate the method of obtaining the equation, an actual numerical case follows.

Fig. 1 shows the i_g-e_g curve of a typical 327 tube. This has been re-plotted in Fig. 2 on logarithmic coordinates, and may be considered a straight line for small values of i_g. In this case the equation has the form

$$i_g = ae_g{}^m \tag{1}$$

However, it is seen that the difference between i_g and the values given

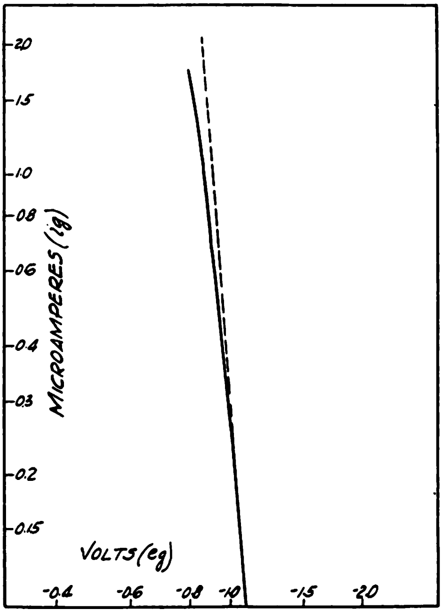

Fig. 2

by (1) becomes greater and greater with increasing e_g. Equation (1), therefore, must be corrected by a constant negative term i_0, viz.,

$$(i_g - i_0) = ae_g{}^m \tag{2}$$

Substituting into (2) the coordinates of three well-separated points of the $i_g - e_g$ curve there results

$$0.09 - i_0 = (1.10a)^m \tag{3}$$

$$0.46 - i_0 = (0.95a)^m \tag{4}$$

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$$1.78 - i_0 = (0.80a)^m \tag{5}$$

Subtracting (3) from (4):

$$0.37 = (0.95a)^m - (1.10a)^m$$

and factoring out the $(0.95a)^m$th term

$$0.37 = (0.95a)^m [1 - 1.158^m] \tag{6}$$

Performing a similar operation on (4) and (5):

$$\begin{aligned} 1.32 &= (0.80a)^m - (0.95a)^m \\ &= (0.95a)^m [0.843^m - 1] \end{aligned} \tag{7}$$

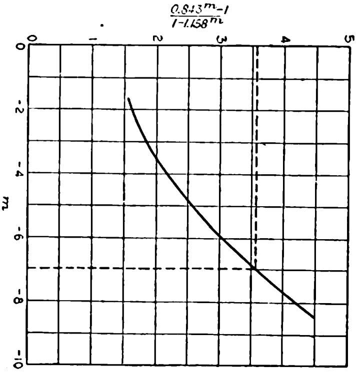

Fig. 3

The ratio of (7) to (6) gives:

$$3.57 = \frac{0.843^m - 1}{1 - 1.158^m} \tag{8}$$

The value of m in (8) must be determined by trial. Various values are substituted for m in the right-hand member of (8) and the values of the fraction so obtained are plotted in Fig. 3. The correct value of m is then the abscissa of the point whose ordinate is the left-hand member of (8), or, $m = -7$.

The values of a and i_0 are then obtained by simple substitution. The resulting equation is:

$$i_g = (0.40 e_g^{-7} - 0.114) \times 10^{-6} \tag{9}$$

Its first derivative is

$$di_g/de_g = -2.80 e_g^{-8} \times 10^{-6} \tag{10}$$

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and its second derivative is

$$d^2i_g/de_g^2 = 22.40e_g^{-9} \times 10^{-6} \qquad (11)$$

Curves calculated from (9), (10), and (11) are shown in Fig. 1. The calculated values of i_g are indicated by circles which fall directly upon the experimentally obtained i_g-e_g curve, indicating the reliability of the equations.

In conclusion, it might be pointed out that whenever inflections are found in the curve, such as often occur at large values of i_g, equations so determined cannot be used. For the smaller values of i_g, however, in the range encountered in practice, these equations are quite accurate.

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ENGINEERING ASPECTS OF THE WORK OF THE FEDERAL RADIO COMMISSION*

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THE administrative and legal aspects of the work of the Federal Radio Commission are complicated and interesting. Much of this complexity and interest can be traced to the peculiar engineering facts of radio transmission. If it were not for the limitations imposed by the nature of radio waves, the Commission would have a relatively easy task, or indeed the Commission might never have been created.

The numerous engineering problems which have to be dealt with in the course of the Commission's work arise mainly from two physical phenomena. These are: (a) radio waves spread out everywhere, stopping at no boundaries, and capable of great mutual interference, (b) the number of radio communication channels is definitely and severely limited. The implications of these basic facts are far-reaching. The first has led to international regulation, now embodied in the 1927 International Radio Convention.

Limited Number of Communication Channels. This, likewise, has international as well as national consequences. The right to operate radio transmitting stations has become so valuable that the demand for channels far exceeds the supply. The number of channels is being increased, from time to time, as radio technique develops, but at any given time there are only a limited number of communication channels. If stations are permitted to operate in excess of the capacity of these channels extensive interference develops and radio operation becomes unsatisfactory.

In the present state of radio technique the number of channels in the whole radio spectrum is as follows: in the low frequencies (15 to 550 kc), there are something less than 1000 channels; in the broadcast band of frequencies (550 to 1500 kc), there are 96 channels, of which 90 are available for the use of the United States; and in the high frequencies (from 1500 to 23,000 kc) there are about 1260 channels. These figures are on the basis of an approximate 0.2 per cent width of channels for frequencies above 1500 kc, a 10-kc width in the broadcast band, and

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a width grading from 0.2 per cent to 1.0 per cent below 550 kc. The factors determining these channel widths are discussed below.

Thus we have a total of about 2350 channels available for the radio traffic of the entire world. On some of these frequencies, particularly the very low and the very high, it is not feasible to have more than one station operating at any given time in the whole world. On many of the others a large number of stations can operate simultaneously. The facts regarding these frequencies are well enough established to permit us to calculate the number of stations which can be licensed without causing excessive interference.

The fact that the number of channels is limited and the number of stations assignable to any one channel is again limited, imposes upon the Government the necessity of choice among applicants for the radio channels. This is the underlying reason why a Federal Radio Commission came to be created. To provide for choice among those who aspire to construct and use radio stations, Congress created not only the Commission as its instrument to make the choice, but also a judicial principle to be the basis of choice, viz., the principle of "public interest, convenience, or necessity."

It was the congestion in the broadcast band which spurred Congress to this legislation. Only in that band of frequencies did the number of applicants for licenses exceed the supply of channels, in early 1927, when the law was passed. The condition extended, however, and the demand now exceeds the supply in the high-frequency band as well as as in the broadcast band. The Commission's task becomes progressively more difficult, and at the same time the stimulus to engineering progress increases.

The number of stations which can be in simultaneous operation without destructive interference depends on a number of factors. First of these is the width of channel occupied by the intelligence transmitted. That is to say, every message or signal actually preempts certain frequencies on either side of that of the radio wave which carries it. Speech or music thus takes up a wider channel than telegraphic dots and dashes. The channel widths required for the various classes of intelligence transmitted by radio are about as follows: for telegraphy, even at very high speed, a few tenths kc or less. For telephony, 10 kc. The same for photograph transmission at maximum commercial speeds. For television of fair quality, 100 kc.

The use of damped waves, produced by spark transmitters, involves even wider channels than any of the foregoing. In fact it is so nearly impossible to conduct radio communication on damped waves without interference that their use has become steadily more objectionable.

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The International Radio Convention of 1927 forbids their use in new stations at frequencies below 375 kc after 1929, and forbids their use entirely (except for ships and aircraft stations, of less than 300 watts) after 1939. The Radio Commission, by its General Order No. 51, forbade their use entirely (except for ship stations) after January 1, 1929.

Another limitation on the number of communication channels available is the lack of perfect constancy of station frequencies. The channels must be wide enough so that frequency variations will not cause a transmitting station to invade the channel of another station. If a station frequency varied as much as 0.2 per cent, the present allowed width of high-frequency channels, this would put it exactly on the frequency of the station occupying the adjacent channel. An accuracy of frequency maintenance much better than 0.2 per cent is therefore necessary to permit the use of channels of this width.

The Commission is therefore requiring high-frequency stations (other than mobile and amateur), to maintain frequency with an accuracy of 0.05 per cent or better at all times; it also requires that transmitters be tuned with an accuracy of 0.025 per cent. This requires very careful design of transmitting apparatus. The use of piezo oscillators or some equivalent means of accurate maintenance is essential.

Another important factor limiting the number of stations that can be on the air simultaneously is the selectivity of receiving apparatus. This, taken together with geographical and frequency separation of transmitting stations, their power, and the location of the receiver with respect to interfering stations, largely determines the allowable channel width at the present time.

High Frequencies. For frequencies above 1500 kc, the known facts regarding these various factors determining channel width (intelligence band width, frequency variation, receiver selectivity, and related factors) indicate that a width of approximately 0.2 per cent is practicable at the present. As the design of receivers improves, giving greater selectivity, and as the constancy with which stations maintain their frequency improves, the channels may be narrowed. The channel width may perhaps soon be reduced to approximately 0.1 per cent, allowing twice as many stations to be licensed, in some parts of the spectrum. There are highly important political consequences of this purely engineering circumstance. Frequencies above 6000 kc are world-wide in their effects, and they are thus subject to division among the nations. The greater the number of available channels, the less is the likelihood of serious international conflict over their exploitation.

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Even in the 1500–6000-kc band, transmissions are continental (although not world-wide), in their effects, and it has been necessary to secure agreement with Canada, Cuba, and other North American nations on their use. Those nations have agreed to use the same width of channel, frequency maintenance requirements, etc., as the United States. Of the 639 channels in this band each North American nation reserved a few for priority use by that nation. Most of them are used in common by all these nations, and agreement has been reached as to the parts of the spectrum in which to license various types of users, such as Government, ship, aircraft, visual broadcasting, experimental, etc., stations.

In January, the Commission had about 850 applications pending for frequencies in the 1500–6000-kc band. These were for all sorts of uses, e.g., ship telephone and telegraph, airplane telephone and telegraph, freight train communication, geophysical exploration, power line emergency service, television transmission, point-to-point commercial message service, broadcasting pickup, relay broadcasting, police signalling, general experimentation, etc. It was by no means possible to grant all these applications. Even though several stations at suitable distances may operate simultaneously on one channel, the total number was definitely limited. In this band, just as in the higher frequencies, the Commission was under the necessity of denying many applications, since their number exceeded the transmission opportunities on the channels available.

There are 624 channels available in the band of higher frequencies from 6000 to 23,000 kc, in which any signal may be heard all over the world. There are already some 1700 stations (other than amateur), in the world operating on these frequencies, an average of about 3 per channel. This frequency band is therefore already fully occupied. Whenever more than one station is operated on a channel there is a potential source of interference. Additions can be made only in special cases, by consideration of the areas affected, times of operation, differing capacities of the various frequencies at different parts of the diurnal period, and engineering expedients like directional reception transmission. The real nature of the congestion is apparent from the fact that the Commission has been forced to deny hundreds of applications for licenses in this frequency band.

The frequencies above 6000 kc are suitable for very long distance transmission and are, therefore, of great international importance. They have been appropriated as needed in the various countries without any agreed plan or basis of assignment. Congestion has now begun and an international agreement on their allocation will soon

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be imperative. This is expected to be one of the major subjects of discussion by the meeting of the International Technical Consulting Committee on Radio Communications, which is expected to meet at The Hague in September.

Public Interest, Convenience, or Necessity. The interpretation and application of this phrase is a novel development in jurisprudence. The phrase is borrowed from legal terminology used in the regulation of public utilities, such as street-car lines and gas companies. Radio transmitting stations are not public utilities, and yet the test of a public utility must be applied to them for the two basic reasons already given, viz., the potential interference of each radio transmission with every other, and the fact that the number of channels is sharply limited.

The test of "public interest, convenience, or necessity" is being applied in broadcasting to mean that the rights of the listeners are superior to those of the broadcasting stations. This means that, as far as possible, interference must be avoided. It means that rural listeners, remote from any station, as well as city listeners, must be given service. It means that excessive duplication of programs by many stations cannot be permitted, and that high-power stations cannot be located in the midst of large populous areas. Perhaps the most important implication is that the total number of broadcasting stations must be limited to the number necessary to prevent undue interference. Each of these correllaries of a purely legal principle requires extensive engineering data for its application.

Broadcasting. The broadcasting band, which has hitherto occupied the chief attention of the Commission, exhibits a number of very special engineering problems. Here the width of each channel is 10 kc, which is necessary for satisfactory musical reception. Even this is not sufficient for musical reproduction of the highest quality. With only 90 such channels, and more than 600 stations on them, there was naturally very great interference prior to the November, 1928, allocation. To remedy this the Commission had to choose among various alternatives. It decided as a matter of policy not to reduce radically the total number of stations. It was then necessary to (a) limit the simultaneous operation of an excessive number of stations be making many of them divide time; (b) assign frequencies carefully selected with regard to geographical separation of stations, to reduce inter-channel interference (i.e., disturbance of reception of a station on one frequency by other stations on adjacent frequencies); and (c) limit the power of stations so they would not cause interference to other stations on the same frequency.

The accomplishing of this constituted the allocation of broadcasting

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stations which the Commission put into effect on November 11, 1928. For a detailed description of the allocation from the engineering viewpoint, see my article.[1] The principal features of the allocation are indicated in the following table:

	High-Power, 5 kw and up	Regional, 500–1000 w	Limited Service		Local, 10–100 w	Total
			5 kw	1000 w		
Number of Channels	40	35	4	5	6	90
Station Assignments per channel	1	2½	2½	5	25	—
Number Station Assignments in U. S.	40	90	10	25	150	315
Number Station Assignments in each zone	8	18	2	5	30	63

The expression "station assignment" indicates full-time operation 24 hours a day, by a station, or by a group of stations sharing time.

The most striking of the problems involved in the allocation was the carrying out of requirement (c), which determines power limitations. Stations assigned to the same frequency have not, up to the present, been able to maintain their frequencies with sufficient accuracy to prevent the existence of a slight difference (or beat) frequency, producing what is commonly known as heterodyne interference, or whistles. Unfortunately the heterodyne interference reaches out to enormously greater distances from a station than the program. Consequently the operation of two or more stations on a channel results in an area of destructive interference far in excess of the area in which program service is provided. For instance, the program of a 5-kw station can be heard with fair intensity under good conditions at 100 miles, while the heterodyne interference from two such stations is heard at 3000 miles. Two stations of 5 kw or more therefore cannot be assigned the same frequency in the United States. It is possible, on the average, to put two or more 1-kw stations on the same frequency if they are at least 1800 miles apart, and two or more ½-kw stations if they are at least 1200 miles apart. All stations subject to these restrictions have only a small service area, and give no service to remote rural areas. Such distant service is given only by stations having exclusive use of the channels to which they are assigned.

In order to provide rural service, 40 channels are each used by one station exclusively. The stations on the exclusive channels not only serve very great areas, but deliver a more satisfactory intensity at every point within those areas. Their service is better for all concerned,

[1] "Analysis of Broadcasting Station Allocation," Proc. I. R. E., **16**, 1477–1485; November, 1928.

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the greater the power they use. This fact is not commonly understood by others than radio engineers. It is clear when the distinction between the exclusive and the other channels is comprehended. Service on the non-exclusive channels would be utterly ruined if the power limits fixed by the facts of heterodyne interference should be exceeded, and in consequence such stations cannot in general use more than 1 kw. But on the exclusive channels the service is better the higher the power level, and indeed such stations will not be serving the public most effectively until the level reaches hundreds of kilowatts.

There is some hope that the limitation of power and service on the non-exclusive channels may be overcome. If the frequencies of stations on the same channel are maintained to a certain very high accuracy, the heterodyne or whistle becomes inaudible. The technique of frequency control is fast approaching this goal and success has been attained in isolated instances.[2] The satisfactory service area of such "synchronized" stations is not yet known. It is likely that some additional fading and interference effects will be introduced, but it is believed that the net service area will be substantially greater than when heterodyne interference exists. The significance of this is that the present power limits for stations on shared channels can be raised, better service given, and wider areas served. Synchronization is therefore looked for as the next great advance in broadcasting.

This discussion of broadcasting has been largely with reference to night conditions. Broadcast transmission is entirely different in the daytime. Transmission distances are much less, and somewhat greater power can be allowed the stations. Furthermore, additional stations can be licensed for daytime operation only. While the problems are not as acute as are those of night-time transmission, they are being handled with care so that daytime broadcasting may be developed as a valuable service.

The difference between day and night transmission conditions raised one technical problem of considerable moment, viz., determination of the time when day ends and night begins, and thus at what hour daytime stations should close. Investigation had revealed that the change from day to night radio conditions extends over a period of something more than an hour and a half, beginning about a half hour before sunset and closing an hour after sunset. The most reasonable time to choose as the transition point is the moment of sunset, and this was done in the Commission's General Order No. 41.

Most of the regulations of the Commission involve engineering

[2] J. H. Dellinger, "The Status of Frequency Standardization," Proc. I. R. E., 16, 579; May, 1928.

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problems. Examples include the General Orders on chain program limitation, visual broadcasting (television), increased power in daytime, and prohibition of damped waves. The Broadcasting Committee of the Institute of Radio Engineers has been of great assistance to the Commission by the studies it has made of certain subjects leading to new regulations. These are on such subjects as: the requirement of an artificial antenna in broadcasting stations for use during warming-up periods, etc.; the location of high-power stations with respect to populous areas; requirement of highly accurate frequency control; allowable ratio of day to night power; permissible intensity of harmonics; percentage modulation; and fidelity of transmission.

Conclusion. All of the engineering work involved in federal radio regulation has the peculiar difficulty that the facts dealt with are extremely complex. They are indeed rapidly shifting. Not only must allowance be constantly made for the flux of changes inherent in a rapidly developing art, but radio waves themselves exhibit extraordinary vagaries. Orderly radio regulation must proceed on a consideration of the distances at which the waves are received. But distances vary enormously between day and night, from season to season, even from night to night, and are different over different kinds of terrain. Knowing this is not to counsel despair. These vagaries have, after all, certain discernible laws, becoming more and more calculable as the results of scientific investigations accumulate. It is not necessary to throw up our hands and say that the whole situation is chaotic. In spite of their vagaries, radio phenomena are subject to known engineering principles. An engineering principle is nothing but an organized body of facts affecting a practical situation. Violation of such engineering principles in radio regulation would sooner or later reduce the service of radio to the public.

Summarizing, the federal regulation of radio involves extensive and difficult engineering problems. These are characterized by certain outstanding facts or principles. First, radio waves spread out everywhere and potentially interfere with one another. Secondly, at any given stage of radio technique, the available number of communication channels is definitely limited. Another controlling principle, as the art stands today, is that heterodyne interference sharply limits the power that may be permitted any two or more broadcasting stations on the same channel. Finally, radio wave transmission is characterized by extreme vagaries. The facts and implications of each of these principles are subject to constant revision as radio progresses. Such facts constitute the natural limitations of radio. They are inescapable conditions of its government regulation.

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SOME CHARACTERISTICS OF MODERN RADIO RECEIVERS AND THEIR RELATION TO BROADCAST REGULATION*

By
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Summary—*The paper gives a brief discussion of the modern tendencies in radio broadcast receiver design, with particular regard to those characteristics of receivers which are related to the problem of allocation and regulation of broadcasting stations. These characteristics are separated into five classes, as follows: (1) discrimination between channels; (2) discrimination within a channel; (3) uniformity of reception in all channels; (4) uniformity of reception within a channel; (5) range of reception. The conclusions are based upon experimental studies of a large number of broadcast receivers which have been sold commercially, and others which will be sold during the present year.*

RADIO broadcast regulation must deal generally with the problems of providing acceptable radio service to the greatest number of listeners from the greatest number and diversity of sources. In the absence of the unified control of all transmitting and receiving units which is possible in a wire distribution system, constructive regulation frequently involves the reconciliation of interests which are in definite conflict. Congestion of the medium of propagation is inevitable when satisfactory broadcast service requires channel widths approaching 10 kc for sound broadcasting and 100 kc for visual broadcasting. Thus technical developments in broadcast receivers, as well as in broadcast transmitters, are related to the problems of regulation insofar as they promote or retard the most effective utilization of the medium. It is from this viewpoint that the modern tendencies in receiver design are to be discussed. For convenience, the significant characteristics of broadcast receivers will be considered separately, although on account of their interrelations such a division is largely formal.

1. Discrimination Between Channels

One of the most important elements determining the "acceptability" of broadcast service is the extent of the listener's privilege of discrimination between programs. The10-kc separation between channels

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in the broadcast band is one of the few features of American broadcasting which is so well established by regulation and practice that it is unlikely to change in the near future. Modern receivers of what might be termed medium quality and cost are quite generally able to suppress crosstalk from an unwanted signal in the adjacent channel which has the same field intensity as the wanted signal. But it is an inherent characteristic of the existing system that thousands and perhaps millions of listeners are in a region of intense fields from a powerful station, usually of high quality and operating on a cleared channel. The average radio listener is probably permanently reconciled to sacrificing service from the weak stations on adjacent channels for the privilege of obtaining a genuine service field intensity from the high quality station. It is therefore unprofitable for the designer of receivers even to attempt to provide equipment capable of giving service on any one of the 96 American channels at the will of the operator, as a *normal* operating condition. Efforts at improvement in the selectivity of receivers can probably be best directed toward equalizing the selectivity at all parts of the broadcast band.

Practically all types of commercial receivers, including double-detection sets, are now progressively less selective toward one end of the band, usually the high-frequency end. In this respect there has been a perceptible tendency toward improvement in the past two years. This statement is based upon an examination of twenty different receivers offered for sale by American manufacturers in the radio season of 1927–28, and a second group of twenty-four different receivers sold during 1928–29.

The 1927–28, receivers, which will be called group *A*, include almost all the most widely used commercial types, as well as certain types which were for some reason distinctive. In the latter class of group *A* falls one receiver in which the entire selective system is concentrated in a filter between the antenna and the first amplifier, and two receivers having provision for unusually high output levels. With one exception all the receivers of group *A* are designed for antenna operation and all include a single detector. The high-frequency amplifiers of all receivers in the group employ triodes exclusively, and are variously stabilized; some by adjusted losses, some by combinations of losses and partial reactive balance, others entirely by reactive balancing circuits of various types. Four of the group are provided with five tuned circuits, eleven with four tuned circuits, and five with three tuned circuits. The receivers of this group were sold at retail for prices ranging from $85.00 to $440.00.

The second group of receivers, which will be called group *B*, includes eighteen receivers which are on the market at the time of this

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writing, and six which are scheduled for production during 1929. Group *B* is made up chiefly of antenna operated receivers, all designed for alternating-current supply. It includes two double-detection sets and several sets in which the high-frequency amplifiers employ screen-grid tetrodes. Two receivers include five tuned circuits, fourteen include four tuned circuits and eight include three tuned circuits.

Groups *A* and *B* were so chosen that collectively they furnish a fair picture of design and performance of American broadcast receivers. The characteristics which are to be discussed were determined by a standard experimental technique similar to that recommended in the "Preliminary Draft of Report of Committee on Standardization" as drawn up by that Committee of the Institute in 1928. In the case of tests on single factory-built receivers, each set was adjusted to yield the best performance irrespective of accidental faults, in order to obtain as nearly as possible the ideal data characteristic of each particular design.

Obviously a complete description of the ablity of any given receiver to reject unwanted signals should include an examination, at several spaced frequencies in the broadcast band, of the response of the receiver to interfering signals in two or three adjacent channels on each side of the wanted frequency, since the frequency-response characteristics of all receivers generally exhibit different shapes in different parts of their service range. But for a comparison of a large number of receivers the complications involved in such a detailed study tend to make adequate generalizations impossible. In the present discussion, therefore, attention will be confined to the relative responses of a receiver to a wanted signal and to an unwanted signal of the same field intensity in the next adjacent channel, that is, having a carrier separated by 10 kc from the carrier of the wanted signal. A conservative though generally accepted arbitrary figure for the greatest tolerable interference level is one thousandth of the power output provided by the wanted signal. In other words the unwanted signal should be 30 db below the wanted signal.

Out of the twenty receivers of group *A*, compared at 1000 kc with a wanted signal having 30 per cent modulation at 400 cycles, and an equal unwanted signal 10 kc away, in five sets the unwanted output level is 30 db or more below the output from the wanted signal, and in four sets the unwanted signal is less than 20 db down. In eleven sets, including most of the popular types, the interference level is between 20 and 30 db below the signal level with a general average of 23 db. At frequencies of 600 kc and less the interference signal in an adjacent channel produces an output 30 db or more below the wanted signal in every one of the twenty receivers.

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Comparing on the same basis the twenty-four receivers of a year later comprising group *B*, we find no appreciable difference from group *A* at 600 kc, but a perceptible improvement at the higher frequencies. At 1000 kc eleven of group *B* yield an unwanted output 30 or more db below the wanted output and only four show a discrimination of less than 20 db.

From the standpoint of regulation it is probably not desirable further to complicate the existing problems of geographical assignments of power and channels by attempting to take account of the non-uniform selectivity which still characterizes most receivers, since it is physically possible to equalize the selectivity of a receiver at all parts of the broadcast band.

2. Discrimination Within A Channel

Discrimination against certain side frequencies in a received signal occurs in all radio receivers both before and after demodulation. Under the existing system of channel separation, unwanted frequencies are usually present in the channel of reception, as well as outside of it. The appearance in the output of a receiver of all demodulated side frequencies lying between the carrier and the boundaries of the channel is not necessary for good reproduction. The transmission through a receiver of frequencies 9 to 10 kc removed from the carrier is undesirable on account of the existence of beats between carriers on adjacent channels, and also on account of the undesirability of opening the door to electrical "noise" any wider than is required for acceptable reproduction of complex music. Also, the passage of frequencies within about 15 cycles of the carrier will become less desirable as progress is made in the operation of synchronized or approximately synchronized transmissions from stations whose service areas overlap. In most modern receivers which exhibit the greatest degree of frequency fidelity the 20-cycle output is negligible and the output levels even at 5000 cycles are from 15 to 20 db below those at 1000 cycles. In the twenty receivers comprising group *A*, comparing the electrical output at a modulation frequency of 50 cycles with the electrical output at 400 cycles we find only one receiver whose 50-cycle output in less than 4 db below the 400-cycle output, ten receivers whose 50-cycle output is between 6 and 10 db down, five whose 50-cycle output is between 10 and 30 db down, and four whose 50-cycle output is more than 30 db below the 400-cycle output. In the same group the 5000-cycle output of four is less than 4 db below the 400-cycle output, the 500-cycle output of six is between 6 and 10 db down, six more are between 10 and 30 db down, and in two the 5000-cycle output is more than 30 db below

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the 400-cycle output. In the twenty-four receivers of group *B* five are less than 4 db down at 50 cycles and thirteen are between 4 and 10 db down at this frequency. But in the same group at 5000 cycles all receivers yield a 5000-cycle output which is 10 db or more below the 400-cycle output and five are more than 35 db down at 5000 cycles. All of these data on both groups are for a carrier frequency of 1000 kc.

Thus the modern tendency in receiver design appears to be still the progressive accentuation of the lower frequencies even at the expense of the higher frequencies within a channel. In all of the most recent receivers, however, the output at 20 cycles or at 7000 cycles is more than 40 db below the speech-frequency output. Many modern loud speakers yield a sound response at 50 cycles which is perceptible compared with the 400-cycle response. Some loud speakers, not provided with so-called overload filters, do not exhibit a significant cutoff below 8000 cycles. But there is little likelihood of such an improvement in the frequency fidelity of the complete receiving system that it should be considered in making allocations under the existing system of channel separation. It is well to bear in mind, however, that the ultimate ideal of receiver fidelity is not perfect uniformity of output from 0 to 10000 cycles.

3. Uniformity of Reception in All Channels

There is a steady increase in the uniformity of the response of the radio-frequency filter and amplifiers in commercial receivers over the broadcast band. Out of a group of 20 antenna-type receivers comprising group *A*, ten exhibit a variation of overall sensitivity greater than eight to one between 550 and 1500 kc and only six showed a variation in overall sensitivity of less than three to one. In the more modern receivers comprising group *B*, nine exhibit a variation in sensitivity of less than three to one, eleven show a variation lying between the limits three to one and eight to one and only six vary over a range greater than eight to one. It is interesting to note, however, that even in 1929, at least two receivers of a "popular" type are over fifteen times as sensitive at 1500 kc as at 500 kc. With sets of this type, operated from a standard antenna, and adjusted for normal output on a signal at 1500 kc, a signal of equal field intensity at 700 kc or less would be inaudible. This situation may be contrasted, however, with the case of another receiver in group *B* which for purposes of discussion will be called "receiver *X*." This set is also in the "popular" class of price and distribution and in certain features represents the most advanced progress in modern design. At no frequency within the broadcast band does the sensitivity of receiver *X* depart more than 15 percent from the mean

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sensitivity. It is provided with a linear detector. Thus if signals of equal field intensity were received in each channel between 550 and 1500 kc without readjusting the sensitivity control, the total variation in output would not exceed 2.3 db.

4. Uniformity of Reception Within A Channel

The question of frequency fidelity has already been discussed in Section 2 above, as a matter of discrimination against unwanted frequencies.

Amplitude fidelity involves the presence of non-linear reponse and harmonic generation in the demodulator as well as in all amplifiers. The maximum distortionless output level provided by the audio-frequency amplifier should be generally determined by the preferences and the esthetic taste of the listener, and bears no direct relation to the matter of regulation of broadcasting. Until the year 1928 there was a rapid and progressive increase in the distortionless output capacity of all receivers from levels of the order 0.1 watt up to 6 or 7 watts. Present indications are that the pendulum is beginning a limited reverse swing in the interest of economy, with the advent of more sensitive high-quality loud speakers. The average output level of current radio receivers is of the order 1.5 watts. The question of overload in the carrier-frequency or medium-frequency amplifier has some bearing on the problem of location of powerful transmitters with respect to populous areas. The modern tendency in this respect is entirely constructive. It consists of a growing disposition on the part of designers of receivers to improve and increase those elements of the radio-frequency filter system which precede the first tube in the receiver, and to discard the practice of connecting the first tube directly to an aperiodic antenna system.

The improvement in amplitude fidelity which has the greatest significance, as regards effective utilization of the propagation medium, is the use of demodulators from which the output is proportioned to the percentage modulation of the incoming signal over a range from zero to about 90 per cent, and in which the harmonic generation is negligible even at high modulation levels. The technique of such opeation is now fairly well known, and the advent of high-gain radio-frequency amplifiers provides a timely expedient for the economical application of this technique. In the receivers of group *B*, five employ demodulators of this general type, variously known as "power detectors" or "linear detectors." It was formerly customary to operate the main demodulator in a receiver at an input level of the order 0.1 volt for normal signal output. Input levels from 2 to 10 volts are now not unusual.

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In receiver X, mentioned above, the voltage gain from the first amplifier grid to the demodulator grid is approximately 50,000. The purpose of this gain is not to provide an excessive overall sensitivity, but to operate the demodulator at an input level of about 3 volts. The average overall sensitivity of the receiver is only 80 microvolts. The maximum distortionless output level from the single low-frequency amplifier stage is 3.2 watts. The demodulator, which feeds this stage, exhibits no appreciable overload distortion up to amplifier output levels of 3.2 watts unless the modulation falls below the extreme figure of 2 per cent.

The use of linear demodulators provides reproduction of good quality from broadcast transmitters of high modulation capability.

A general increase in the average modulation levels of transmitting stations is a most important and useful means of increasing service areas without increasing the beat note interference areas, and some minimum level on modulation capability of transmitters may ultimately be imposed by the government.

5. Range of Reception

The sensitivity of the radio receiver of course has a definite bearing upon the coverage areas of broadcasting stations. But it is now generally true that receivers in the low and medium classes of price are sufficiently sensitive to produce suitable entertainment outputs on field intensities of from 25 to 50 μv per meter in the absence of fading or electrical noise. Field intensities which are regularly depended upon for radio service vary tremendously from one section of the country to another, even today. But owing to the fact that the character and inclination of the "average" radio listener are undergoing a steady change toward the use of radio broadcasting as a means of entertainment from the programs themselves, and not as an indoor sport, the maximum sensitivity of the average broadcast receiver is well above that which can be consistently and satisfactorily employed. The growth of chain broadcasting has also contributed to this situation. In the past two years, moreover, there has been a definite trend away from the attitude that the best radio receiver is the one which has the greatest attainable sensitivity, and designers of receivers are now generally abandoning the practice of adding to the cost of a set to provide a maximum sensitivity of 5 μv or more. The tendency even in the most elaborate receivers is to choose a sensitivity of 20 to 50μv or even less, and to apply the high-amplification features of modern tubes directly to the provision of better reproduction, higher distortionless output levels, or to the automatic control of output.

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In group *A* of receivers referred to previously, seven exhibit a mean sensitivity between 10 and 100 μv and thirteen exhibit a mean sensitivity between 100 and 1000 μv. In the later group *B*, eleven exhibit a mean sensitivity between 10 and 100 μv and ten show a mean sensitivity between 100 and 1000 μv. These figures on sensitivity relate to a signal modulated 30 per cent at 400 cycles. The voltages mentioned are those values which when impressed upon the receiver through a local antenna circuit of standard constants, produce an audio-frequency electric output of 100 mw. Thus if a receiver has a sentivitiy of 100 μv it will yield this output level from an antenna of 4 meters effective height exposed to a field of 25 μv per meter.

As broadcast reception becomes more a matter of service and less a question of chance the noise levels and fading characteristics of the incoming waves become more important in determining the merit of the service than the absolute magnitudes of the average field intensity. The introduction and development of automatic "volume controls" for broadcast receivers is a more significant development than any changes in the sensitivity of receivers that are likely to occur in the future. Devices for holding the output level to within a maximum variation during a variation of over 500 to 1 in field intensity are now available in practical commercial form. A general public acceptance of such controls may not be immediate. But receiver designers will undoubtedly find it commercially profitable to refine the technique of automatic control until a stage is reached where the practical elimination of the effects of fading will bring about a general increase in the accepted service areas of most broadcasting stations.

Aside from the improvements introduced by a general increase in modulation levels accompanied by the corresponding alterations in methods of demodulation in the receiver, there is as yet little prospect of increasing the discrimination of broadcast receivers themselves against atmospheric and local noises. It may be that the further advances in this direction will be delayed until the natural processes of evolution produce a type of human ear or artistic taste which is universally satisfied by music containing no frequencies higher than two or three kc.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 8 *August, 929*

THE REGULATION OF BROADCASTING STATIONS AS A SYSTEMS PROBLEM

By

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ABSTRACT

This paper is a brief discussion of some of the outstanding technical problems of radio broadcast regulation with particular reference to the transmitting equipment. It is pointed out that in the interests of continued progress the regulatory program should be based on the following considerations:

(1) Intensive development of the available frequency band:
(2) Close adherence to the technical facts;
(3) Definite expression of performance standards in proper quantitative terms.

A number of the more important transmitter problems are discussed from this standpoint, including the power rating of stations, increments of power, degree of modulation, location of stations with respect to populous areas, permissible intensity of harmonics, frequency, stability, and fidelity.

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SOME PRINCIPLES OF BROADCAST FREQUENCY ALLOCATION*

By
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THE technical problem of broadcast allocation in a given country is to assign the available radio channels to stations in particular localities in such a way as to give the best possible broadcasting service to the people of the country as a whole. The first consideration is the number of channels which are available for assignment.

In the frequency band 550 to 1500 kc the separation between adjacent channels may be taken as 10 kc, thus giving 96 channels in this range. This 10-kc separation has now become well established in practice, and while there are some reasons to feel that a wider separation would be desirable in order to facilitate the satisfactory transmission and reception of very high quality broadcasting, it seems likely that by a suitable geographical separation between the points to which these channels are assigned it will be possible to employ adequate frequency band widths and still avoid undesirable crosstalk.

While it is convenient to make specific reference to the United States, the general principles under discussion are, of course, applicable to any continental area. At the present time in North America, six channels in this frequency range are used exclusively by Canadian stations, 79 are used exclusively by stations in the United States, and 11 are shared by stations in both countries. This gives a total of 90 for assignment in the United States.

Fundamentally a given channel may be used for either of two kinds of radio broadcasting service depending upon the number of stations which are authorized to operate on that channel.

1. A channel which has but one station operating at a time. On a channel used in this way, a high grade of service can be given to the people in the immediate neighborhood of the station. It is, moreover, only on such a channel that service can be given to broad rural areas. Every opportunity is afforded to take advantage of times when transmission takes place over long distances and thus to serve regions which are not adequately provided with nearby stations. Generally speaking, every channel of this

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kind should carry a program of the highest grade, transmitted from a station in which the highest available power and the best technique are employed. Such a channel provides 24 hours of station operation per day, that is, 24 channel hours for the entire country.

2. A channel which has two or more stations operating simultaneously. On a channel used in this way service is given to a number of separate localities, each of rather restricted area. There is, in general, little or no service to be expected in intermediate areas. Channels assigned in this way are, therefore, most useful for serving the cities near or in which the stations are located and are not satisfactory for rural reception. The relative amounts of power employed by the stations on a channel of this kind determine very largely the sizes of their respective service areas. Such a channel provides 24 hours of station operation per day (24 channel hours) to each of several separate local areas.

Assuming that the assignments made on channels devoted to either type of service can be so arranged as to make most effective use of the possibilities of radio transmission, the problem becomes one of determining what is the proper balance between the two kinds of coverage—rural and urban—in order best to serve the people of the broad area involved.

It may be taken as axiomatic that if broadcasting is to be free from continual reallocations and is to consist of a fairly stable system for the transmission of programs to the country as a whole, there must be a fundamental basis in accordance with which both of these general classes of assignments are apportioned to the various parts of the country. After a basis for apportionment has been established and the number of assignments available in a given locality determined, the problem then becomes the selection by the Federal licensing authority of the stations in that locality which can be expected to best serve "public interest, convenience or necessity." While the particular stations licensed in a given locality might not continue indefinitely to be the ones which would serve the public best, the substitution of one station for another on a given frequency assignment would not involve major changes in the frequency assignments to stations in other parts of the country.

It is thus seen that the problem involves two fairly distinct and separable steps; first, the allocation of the channels in accordance with some scheme which will designate approximately the area or areas in which the station or stations to use the channels should be located; and, second, the designation and licensing of the particular

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stations selected to occupy the available assignments. The purpose of this paper is to consider primarily only the first of these two steps. Each channel assignment to a locality provides 24 operating hours or channel hours. The way in which these hours may be divided up among individual stations by time division is again a matter largely outside the scope of the present paper.

It is conceivable that the basis on which assignments would be apportioned to different parts of the country could be that of population. It is similarly conceivable that an apportionment could be worked out entirely on the basis of area or one could be based on a combination of population and area. Obviously, also, an entirely arbitrary rule might be formulated, which, once established, could be used as a basis for assignments by the Federal licensing authority. Whatever the rule may be it seems essential that there be some such basis on which to build the broadcasting structure of the country. In view of the tremendous competition for the privilege of broadcasting there must be some way in which the licensing authority can determine where to place the limit on the number of stations to which assignments can be granted.

One basis for the apportionment of broadcasting facilities to the various parts of the United States is given in the 1928 amendment to the Radio Act of 1927. The basis embodied in this act is largely one of population. It is provided that broadcasting facilities shall be apportioned equally to the five zones into which the country is divided. Each of the first four zones has a population of approximately 27 million people. The fifth zone has a population of about 12 million, but its area is very large. The law further provides that, each zone having been given its equal share of facilities, the several states are to have shares of the zone total which are substantially proportional to the state populations.

While the present radio law of the United States specifies that so far as possible wavelengths, power, licenses and time of operation shall be apportioned in the way indicated, the most fundamental thing involved is the apportionment of wavelengths and time of operation. More exactly, this means the apportionment of "channel-hours" to stations. The right to operate for 24 hours a day on a given broadcasting channel in a given locality constitutes what may be designated a "full-time assignment." The fundamental limit which is the very cause for the existence of the problem of broadcasting allocation is in the number of assignments available for evening use.

This problem of broadcasting apportionment is not peculiar to the United States. It is before the countries of Europe as a very pressing

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problem. The European broadcasting stations are, in general, using frequencies or channels apportioned according to a plan known as the "Geneva" plan, although, in view of the somewhat informal basis on which the plan was worked out it is not being strictly followed by all

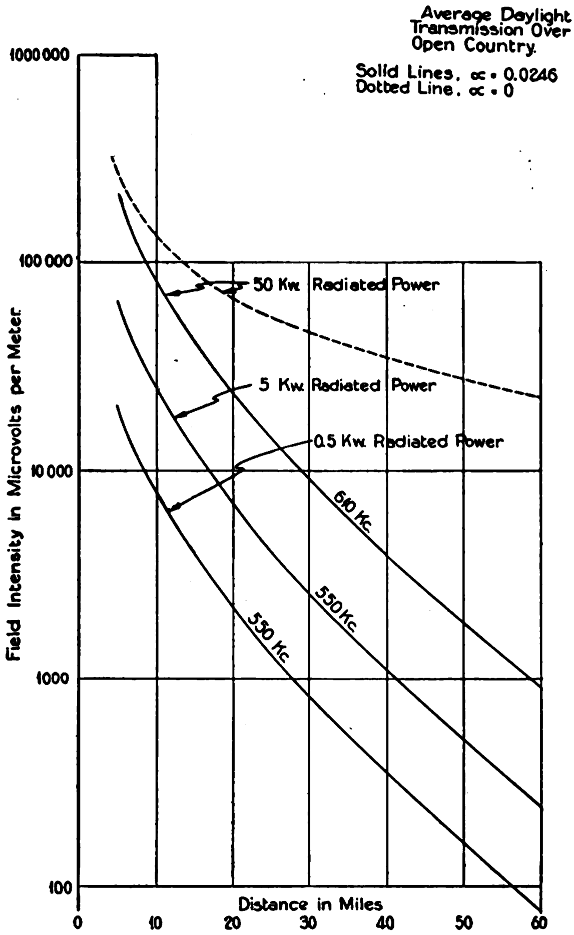

Fig. 1—Relation between Field Intensity and Distance of Transmission.

European broadcasting stations. The two basic plans have recently been suggested in Europe; one, known as the "Lemoine" plan;[1] and another, as the "Poland" plan.[2] Both of these plans contain tables in

[1] Siffer Lemoine, "Allocation of European Broadcast Wavelengths—Some New Points of View," *Experimental Wireless and Wireless Engineer*, pp. 386–396; July, 1928.

[2] "The Problem of International Distribution of Broadcast Wavelengths," *Experimental Wireless and Wireless Engineer*, pp. 3–8; January, 1929.

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which relative quotas of broadcasting assignments are suggested for all of the European countries. Each of these plans involves both population and area, and in the Poland plan, consideration of existing stations, different weights being given to different factors in arriving at a combined basis.

There are some reasons why the population density should be an important factor in determining a sound basis of apportionment, but it seems desirable that a basis be established which, in addition, takes account of the fact that the strength of radio signals in the broadcasting range becomes less, generally speaking, the greater the distance over which they have travelled.

It is interesting to consider the single and multiple types of channel assignment in turn and to look at some of the facts of radio transmission which need to be kept in mind in determining the usefulness of these two kinds of channels.

1. Channels, Each Having Only a Single Full-Time Station Assignment. These are sometimes called "clear" channels.

The fundamental thing to consider in the case of a clear channel is the nature of radio transmission from a single station in the absence of interference from another station on the same channel. The field intensity or signal strength produced by a given radio broadcasting station decreases as the distance from the station becomes greater. Fig. 1 contains some curves showing the relation between the daytime field intensity and the distance over which transmission has taken place.[3] The available data indicate that the signal strength at a distance at night, while varying greatly from time to time, ordinarily falls between two limits. These limits correspond to

(a) The field intensity which is produced under daytime conditions when the absorption is substantially that caused by transmission over a suburban or agricultural type of region, shown by the solid curves in Fig. 1 and,

(b) The field intensity which is produced in the absence of any absorption of power from the transmitted wave and which

[3] These curves are computed from the formula:

$$E = 19.42 \times 10^4 \frac{\sqrt{p}}{d} \epsilon^{-\frac{101.5\alpha d}{\lambda^{0.6}}}$$

E is field intensity in microvolts per meter.
p is radiated power in kilowatts.
d is distance in miles.
λ is wavelength in meters.
The absorption factor α has been taken as 0.0246, which corresponds with measured values of field intensity in many cases of transmission over suburban territory in the northeastern part of the United States.

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corresponds only to the reduction accompanying the spreading of the waves over wider and wider circles. This is shown, for one case, by the dotted curve of Fig. 1.

The limits of the edge of the area served by a given station having a clear channel assignment are affected by

(a) The intensity of the noise—such as static or other electrical interference—which sets a value of signal strength below which reception is unsatisfactory.

(b) The fluctuation in signal or program intensity resulting from the fading of the signal during the course of its transmission. Transmission also is different in different parts of the country and distances which are customarily covered by stations in one locality may be far different from those covered by similar stations in other locations.

Disregarding for the moment the problem of the relationship between assignments on adjacent channels, it seems reasonable that on a clear channel the highest possible field strength and, therefore, the highest possible transmitted power is the condition most to be desired. The location of the station with respect to residential areas is a matter which can be fixed after the amount of power to be used has been determined.

The amount of interference or crosstalk between broadcasting stations on adjacent channels depends upon two major factors

(a) The selectivity of the radio receiver used by the listener who desires to receive one station and exclude the other, and

(b) The *relative* field intensities of the two stations between which selection is to be made.

Assuming that the two stations are about equal in power, the relative field intensities are dependent largely upon the relative distances of the stations from the listener in question. If the field intensities are about equal, that is, if the listener is about midway between the stations, the problem of selection involves merely the selectivity of the radio receiver. If, however, the field from one of the stations is far greater than the field produced by the other, the listener will ordinarily find it much more satisfactory to depend for his program upon the station producing the stronger signal, that is, ordinarily, to listen to the nearer station. Usually also the nearer station produces a program which is freer from fading and in which the static and other noises are less objectionable.

Fig. 2 contains a curve serving as an example of a radio receiver selectivity characteristic. If the receiver is tuned to the frequency *A* of a desired signal, an undesired signal of equal strength produced

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by a second station on frequency B, 20 kc away, will, by the action of the receiving set itself, be reduced by an amount corresponding to the relative heights of the points a and b on the curve. In this example the reduction amounts to 70 decibels. In case the intensities of the signals produced by the two stations are not equal the absolute discrimination effected by the radio receiver would, of course, be different

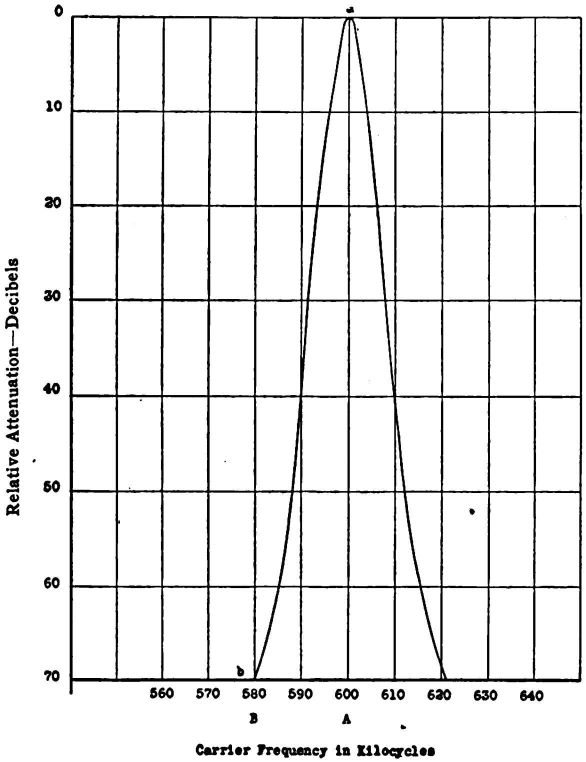

Fig. 2—Curve Illustrating Selectivity of Radio Broadcast Receiver.

although the relative discrimination would be the same. Assume, as another example, that the two field intensities are 50,000 and 10,000 μv per meter, respectively, a ratio corresponding to approximately 14 decibels. If there were no receiver selectivity, the desired detected signal would be about 28 decibels above the desired signal due to the square-law action of the detector. The receiver selectivity of 70 decibels, however, would reduce the undesired signal 42 decibels below the desired signal.

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2. Channels, Each Having Several Full-Time Station Assignments.

On a channel to which several full-time stations are assigned it is, in general, necessary to consider the relative or combined effect, at a given receiving point, of the signals which may be received from two of these stations. Since the stations are transmitting on the same frequency the selectivity characteristic of a radio receiver provides no means of discrimination. The area around a given station within which satisfactory reception is possible is, therefore, that area within which the field or signal produced by any other station on that channel is so small as to be negligible in comparison. The absolute value below which the undesired or interfering field must fall thus depends upon the strength of the desired signal. The variability of radio transmission over substantial distances results in a wide fluctuation in the size of the area within which satisfactory service is produced. The curves given in Fig. 3 indicate the range of variation of the field intensities produced by two stations located 500 miles apart. From this it may be seen that considering a point say 150 miles from Station A the better transmission may at certain times come from station A and at other times from station B, depending on the relative transmission from the two stations at the moment in question. At other times neither station would be heard satisfactorily.

Ordinarily, using types of transmitting equipment which have been in general use up until about the present year, the combined effect of the signals from two stations on a given channel is recognizable as a beat note produced in the radio receiver. The frequency of this beat note is dependent upon the difference between the frequencies of the carrier waves emitted by the two broadcasting stations.

The broadcasting art is apparently just now beginning to accomplish in actual operating practice, a control in the carrier frequencies of broadcasting stations which is close enough to reduce the beat frequency below that which is readily reproduced by the ordinary radio receiver. This will largely eliminate the troublesome heterodyne note. The remaining interference will be in the form of crosstalk between the sidebands of the two stations.

In the example considered in Fig. 3, the area covered by either station may fluctuate between a circle about five miles in diameter and a circle as large as 200 miles in diameter.

There can be considered two general classes of these multiple assignment channels:

(a) Channels on which stations are assigned which have high enough power to cover the maximum non-fading area with a substantial field intensity. Stations on such channels should not

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be too close together geographically if interference on that channel is not to be troublesome.

(b) Channels on which stations having low power are assigned. Since the signals from these stations will only cover a small distance before being so affected by noise as to be unsatisfactory these stations can be assigned closer together geographically.

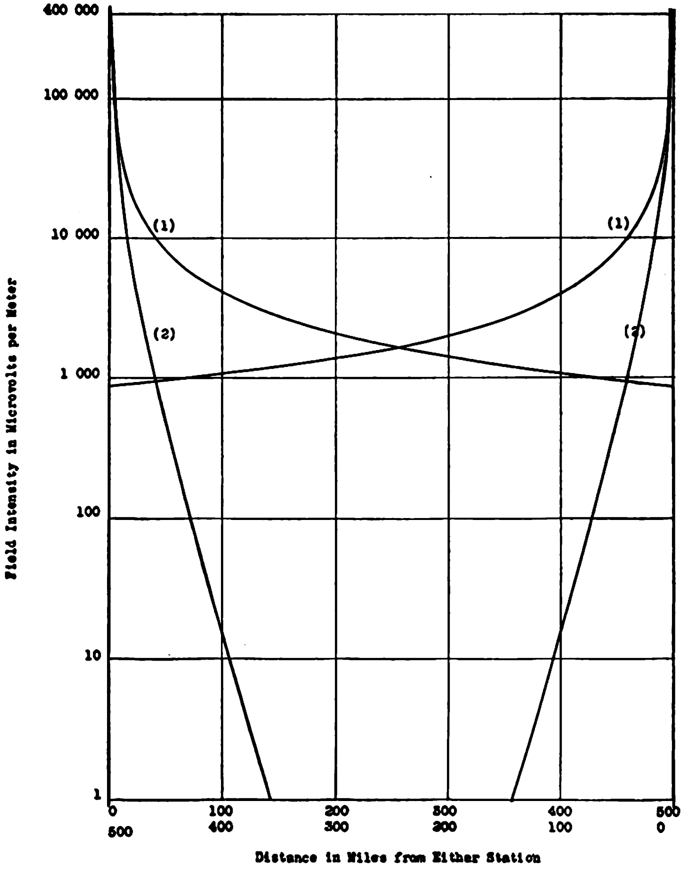

Fig. 3—Relative Intensities of Fields Produced by Two Stations.
(1) No attenuation.
(2) Average transmission over open country—550 kc.

As pointed out above, the general problem of broadcasting allocation involves a determination of the number of available assignments of each of the two kinds under discussion.

One assignment would be available for each clear channel and it may be assumed for the purpose of this discussion that four full-time station assignments could be made to each multiple assignment channel

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in an area such as the United States. (This may, quite surely, be practicable if there is sufficiently close frequency control). The total number of assignments available for the country would be somewhere between the limits of 90 (assuming 90 clear channels) and 360 (assuming no clear channels). The curve on Fig. 4 shows the number of full-time assignments which would be available assuming any particular number of clear channels between these limits. If, for example, 50 channels are given single full-time station assignments, 40 would remain on which multiple assignments could be made. This would give, under the assumptions above, a total of 210 assignments.

The question is sometimes raised of the relative usefulness of channels in different parts of the broadcast band.

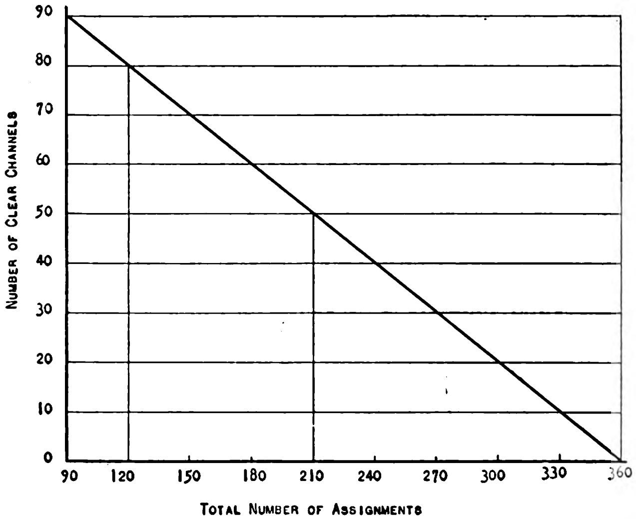

Fig. 4—Total Number of Available Assignments as Related to Number of Clear Channels.

As a general rule, and subject to modification on account of the different transmission in different parts of the country, it would seem desirable that equally high power be used by stations assigned to adjacent clear channels. As may be seen from the curves in Fig. 1, the daytime transmission on the lower frequency channels is ordinarily somewhat better than on the higher frequencies. Since the channels to which single full-time station assignments are made most effective for rural coverage, it would seem desirable that these channels be those which are likely to cover the greatest distances during the daytime regardless of night-time transmission. This would mean that the single

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assignment or clear channels should, other things being equal, be those at the lower frequency end of the broadcasting range. From the broad standpoint of broadcast allocation it would seem desirable to apportion the channels in different parts of the band among the different portions of the country and thus provide equality in this respect as far as possible.

It has been pointed out that while a channel having but a single assignment gives as good rural service as radio makes possible, it gives best service to the region in the general vicinity of the station having that assignment. The distribution of these clear channel assignments might, from this standpoint, be made proportional to population. That is, the number of "single assignment" channels designated for use in each of several regions or "zones" might be made proportional to their populations. If the zones or geographical units to which these clear channels are assigned are fairly large, and the number of them correspondingly small, more flexibility is possible in making assignments to individual stations. The number of stations which may be assigned to a "multiple assignment" channel does not depend at all upon population density but is dependent largely upon distance. The distribution of such assignments among geographical units might from this standpoint, therefore, be made proportional to area. On account of the fact that a fairly large number of assignments of this class is available for a country as large as the United States, the geographical units to which they are apportioned may conveniently be more numerous and therefore smaller than in the case of the single assignment channels. One way, for example, would be to distribute these assignments (on multiple assignment channels) to the several states in proportion to their areas.

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A STUDY OF HETERODYNE INTERFERENCE*

By
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IN the days of radio prior to popular broadcasting, substantially the only use of the word "heterodyne" was as a designation for the type of radio receiver whose invention is generally credited to R. A. Fessenden. This heterodyne receiver was, and still is, the most satisfactory type of system for continuous wave operation. It involved the combination of one set of forces, produced by the received wave, with another set of forces generated under the control of the receiving operator; and hence the name "heterodyne" was coined for it, from the Greek words meaning "other" and "force." A history and description of this receiver, together with certain improvements, is given in an earlier paper.[1]

At the moment the most convenient form of heterodyne receiver utilizes the oscillating audion with either self-contained or separate rectification. For heterodyne reception it is desirable, and indeed practically essential, that the frequency of oscillations generated at the receiving station shall be under exact control of the receiving operator. Such control makes it possible for this operator to choose at will a frequency of beat-note signal response that is best suited to his ear, to his audio-frequency apparatus, and to the conditions of interference. It is well understood that when two continuous radio-frequency oscillations are superimposed and rectified, the result will be a variation of substantially simple wave form having a frequency equal to the difference between the two interacting frequencies. This type of action when applied at radio frequencies has come to be known as the heterodyne principle. It is old in its acoustic and optical analogues, and dates from about 1901 in radio. It is variously used, not only in reception, but also for measurement, for the production of standard frequencies, for frequency transformation in speech-inversion systems, etc.

We now have to consider an interesting situation produced by the organization and growth of an extensive system of continuous-wave radio telephone transmitters operating in the frequency range of

* Dewey decimal classification: R170. Original manuscript received by the Institute, April 11, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

[1] John V. L. Hogan, "The Heterodyne Receiving System", Proc. I. R. E., 1, 75; July, 1913.

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550 to 1500 kc and used for broadcasting. In order to accommodate the maximum number of transmitting stations in this limited band of 950 kc and to allow reasonably high modulation frequencies (2500 cycles without overlap between two stations on neighboring channels), the transmitters have been nominally adjusted or assigned to frequencies separated by 10 kc. Thus, including the terminal frequencies, 96 channels are made available.

If at a given point signals are simultaneously received from two transmitters operating at 10 kc difference in frequency, and if the receiver does not by its selectivity reduce substantially to zero the currents produced by one of the two stations, the rectifier output will contain a 10,000-cycle current. This may easily be picked out of the detector circuit of an average broadcast receiver, by means of a resonant circuit, and amplified sufficiently to operate a loudspeaker having a good response to high audio frequencies. It is ordinarily overlooked by the broadcast listener because its effect is minimized by several cumulative factors. In the first place, the geographical distribution of broadcasting stations and wave frequencies is designed to prevent waves of substantial intensity and only 10 kc difference in frequency from occurring in any part of the United States. Secondly, the usual receiver has an audio system which will not respond strongly at 10,000 cycles. Thirdly, this frequency (which is more than an octave above the fundamental of the highest note on the piano keyboard) is not easily heard by the majority of listeners.

Thus, if there were exact regulation of broadcast transmitter frequencies, there would be practically no heterodyne interference in broadcast reception. But the fact is that broadcast transmitters are permitted to wander from their assigned frequencies by as much as 500 cycles, and often deviate by far greater amounts. This deviation from assigned frequency produces two species of heterodyne effect, either of which may seriously trouble those who are listening in.

The first class of these effects is the result of heterodyne interference between stations nominally operating on adjacent channels, and, therefore, supposed to be 10 kc apart in frequency. If the higher frequency station is actually 500 cycles low while the lower frequency station is 500 cycles high, their difference will be 9 kc. This differential will not ordinarily produce a troublesome background note, for average receiver response to 9 kc is not much better than to 10 kc. But should the two waves be permitted to approach each other still more closely say to 8, 7, or 6 kc, listeners will be disturbed by the well-known "peanut-whistle" accompaniment to their received music and speech. The remedy for this type of heterodyne interference is to insist upon

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maintenance of broadcast transmitter frequencies within less than 500 cycles.

The second class of heterodyne interference produced by frequency deviation is of far greater seriousness to the broadcast service. When a channel is occupied by two or more transmitters operating concurrently, any receiver so located that it can intercept signals of even relatively small field intensity from both stations will have produced in its rectifier output a current variation of the differential frequency. If the two transmitters are operating at exactly the same frequency the differential will of course be zero, and heterodyne interference as it is usually considered[2] will not occur. If either station departs from its normal frequency, however, a continuous a.c. component will appear in the audio system of the receiver. If the net deviation is such as to produce a differential of even 100 cycles, the resulting beat-tone may be quite distressing and if the differential frequency lies between this value and the maximum of 1000 cycles (i.e., the maximum that would be permissible under strict enforcement of the present regulations) the effect upon received speech and music may be even worse. Such frequencies are within the most commonly used musical range, to which the usual audio systems give maximum response, and consequently could not be better chosen if one's intention were to produce the most aggravating character of tone interference.

What can be done to minimize or eliminate this type of heterodyne interference? Nothing so far suggested for use at the receiver has been successful in doing away with audible beat interference unless at the same time it eliminated or reduced the receiver response to musical tones of the same or similar frequencies. Failing a new method of attack at the receiving end (which there seems no reason to expect will be forthcoming) one is driven to consider the transmitter organization.

In general, there are three things that can be done. The obvious and simple cure is to assign only one transmitting station to each channel, i.e., to "clear" all channels. On the present band assigned for broadcasting this would permit simultaneous operation of only 96 stations in the United States and Canada. While with proper location and power for each station such an organization might deliver the most reliable and most varied radio service to the greatest number of listeners, it would not satisfy the present urgent demand for community, local, and regional services. However, insofar as channels

[2] Synchronized or approximately synchronized transmitters may produce various types of interference the discussion of which is beyond the scope of the present paper.

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are and can be cleared the heterodyne interference on those channels is removed and the stations using them are permitted to give the maximum service possible.

Recognizing that a certain number of channels should be devoted to such local and regional services as will permit the assignment of from two to perhaps twenty simultaneously-operating stations per channel, what can be done about reducing heterodyne interference on these channels? The factors one has under control are only the location of each of the stations and the power (and modulation percentage) it is to use, for all the stations on one channel are assumed to operate at the same frequency. But that very assumption brings to light another factor that can be controlled, viz., the deviation from assigned frequency that will be permitted in any case.

Probably the most important of these factors is the matter of geographical location of the stations assigned to any one channel. How important this is can be seen at once by considering two limiting cases. For example, if two transmitters assigned to use the same wave frequency but actually differing by 500 cycles (half the maximum permitted under present regulations) are located immediately adjacent each other, it is obvious that for the same power and modulation their service areas will substantially coincide. However, when both transmitters are in operation neither will be competent to give any desirable program service for the reason that a strong beat tone of 500 cycles (thus having a pitch about one octave above middle C) will be heard in any receiver located in or even well beyond the joint service area. In general, for this case, the beat tone will be louder than the signal modulation of either transmitter. This situation, fortunately, it has been possible to avoid in practice; the condition has existed in each of several localities for a short time both in the early days of broadcasting and recently, but has always been promptly recognized as producing an intolerable type and amount of heterodyne interference.

The antithetical limiting case is that of two transmitters located at maximum distance from each other (say 3000 miles, with reference to the continental United States) and, as before, assigned to the same channel or frequency. Let us again assume that the actual operating frequencies of the two stations differ by 500 cycles. Then the question of whether or not heterodyne interference will exist by reason of a substantial geographical overlap of the two waves will depend upon a number of factors as follows:

(1) The radiated power (and modulation) of each station.

(2) The conditions governing wave transmission at the frequency and at the time under consideration.

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(3) The location of the receiving point with respect to each station.
(4) The sensitiveness of the receiver.
(5) The field intensity of noise at the receiving point.
(6) The character of radio service desired or expected at the receiving point.

It should be obvious that no simple rule can be laid down that will permit immediate determination of the question of whether or not heterodyne interference will result from any given setup of stations. There are, however, a number of practical limiting values that have been determined by long observation of broadcasting conditions, and these may be used to outline more or less completely the border zones that lie between conditions that are certain to produce interference and those that are certain not to produce interference.

Considering the second assumed case, viz., two stations 3000 miles apart and differing in frequency by 500 cycles, we can say at once that as a practical matter no heterodyne interference will be produced if each of the two plants radiates 50 watts of power or less. It may be useful to consider why this is so. In the first place neither station can be expected to produce anywhere or any time a signal stronger than the "unabsorbed" value of its radiation, if our observations can be trusted. Even on the best winter night, then, the signal will be no greater than

$$E_f = \frac{5.8\sqrt{P}}{d} \tag{1}$$

where E_f is field intensity in millivolts per meter, P is radiated power in watts, and d is distance separating sender and receiver in miles.

In the second place, very little useful program service can be rendered at a point so distant that less than 0.1 mv per meter is delivered. By the relation (1) this is seen to be 410 miles from the 50-watt transmitter, under the most favorable conditions. Actually the average night winter-time service will be had over only a much smaller distance for even such feeble signals as 100 μv per meter, but for preliminary interference determination it is safest to assume the maximum transmission distances that can occur.

The next question, then, is what comparative signal can the distant (second) station deliver at a point 2590 miles from the first. Considering again the "unabsorbed" or maximum value, this is shown by (1) to be 0.0158 mv per meter at the distance of 2590 miles. The ratio of desired to interfering field intensities is, then, 100 to 15.8 or 6.32. This low value of the ratio will produce not only strong heterodyne interference but also cross-talk between the stations, but of course

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only at times of most favorable transmission. Such times will occur, however, and probably more often during a winter night as the wave frequency used approaches the 1500-kc end of the spectrum assigned to broadcasting. It is not unusual for 50-watt transmitters to be heard reasonably well at distances of 400 miles. Consequently, it will not be unusual for another 50-watt station to produce heterodyne interference or even occasional crosstalk at the extreme ranges of the first, even though it may be located across the continent.

The obvious conclusion is that if *all* heterodyne interference is to be eliminated from the broadcasting band, stations of power even so small as 50 watts must not be assigned to the same channel, although they are separated geographically by transcontinental distances. But one may well ask whether such extreme protection of the service of a small station is in the best interest of the listeners of the country. Would not more people be better served if some interference with weak signals were permitted, so that groups of listeners centered about each transmitter might be provided with a greater variety of programs at better intensity levels?

For example, let us suppose that a minimum useful signal is of 1 mv per meter intensity, and that, as the measurements of the Bureau of Standards have shown, the average night-time signal has about one-half the "unabsorbed" field intensity. Thus, cutting the coefficient of equation (1) in half, we have the relation:

$$E_f = \frac{2.9\sqrt{P}}{d} \tag{2}$$

A 50-watt transmitter will, on this basis, deliver the assumed 1.0 mv per meter signal at a distance of 20.5 miles. This figure is readily recognized as more nearly what may be expected on average good nights, in the absence of interference, from a 50-watt plant. The second station, now 2980 miles from the receiving point, will produce a signal of only 0.0069 mv per meter, and the ratio of field intensities will be 1000 to 6.9, or 145. Such a ratio is not competent to produce severe crosstalk though it may cause a heterodyne whistle, for it is generally agreed that a value of 100 to 1 is necessary to make crosstalk negligible and of as much as 500 to 1 for the practical elimination of a medium-frequency beat. Nevertheless, with an average ratio of 145 it will be seen that the service zone of 20 miles radius around each transmitter should be free of interference except as a slight whistle drifts in and out.

In the above we have assumed that the two stations differed in frequency by 500 cycles, each being off frequency by 1/2 the amount

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permitted under present regulations. The audio systems of most broadcast receivers are extremely effective at frequencies of 500 to 1000 cycles per second, but relatively inefficient at frequencies of 50 cycles or less. If, then, the stations assigned to the same channel were required to maintain their frequencies to within 25 cycles (as can readily be done with well designed and commerically available apparatus) the pitch of the beat tone could be carried down below the sensitive range and the interference produced by it made little or no more troublesome than that caused by crosstalk. With such frequency control the heterodyne whistle above referred to would be eliminated and the stations would be serving their respective zones without interference.

So far we have given no direct consideration to noise level at the receiving point, although this is the primary factor in selecting the field intensity necessary to produce a service signal. It is well recognized that a signal of 10 mv per meter is necessary to give reliable service where real and continuous freedom from noise is desired, and that even this is inadequate in some cases. Since a field intensity ratio of 100 to 1 gives, with modern receivers, a discrimination of about 40 db in the audio circuits, and since 40 db represent approximately the difference between ordinary speech and an audible but hardly intelligible whisper, one may conclude that average noise levels rise to values well above 0.1 mv per meter. Thus, interference from waves of less than 0.1 mv per meter intensity, if of a frequency not more than 50 cycles from that of the desired wave, may be less troublesome than the noise interference. This would mean that the 0.0069 mv per meter interference occurring in the second case discussed above would often be negligible with respect to noise interference. It explains why, as a practical matter, 50-watt stations need not be kept 3000 miles apart in order to avoid mutual interference under average conditions.

But let us consider the question of increased power. We have seen that two 50-watt plants if well separated may be expected to deliver a 1-mv per meter service in their respective zones of 20 miles radius. If their power be increased to 5000 watts each the same field ratio of 145 to 1 will be had at a point 20 miles from one and 2980 miles from the other, but the field intensities will be multiplied by 10 for the same conditions. In other words, the desired signal will be 10 mv per meter and the interfering signal 0.069 mv per meter. Even this latter value is well below the noise level often observed, but unless the frequencies of the two stations are closely regulated and their differential brought to 50 cycles or less, the interfering whistle will be present

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frequently enough in winter time to be rated as producing heterodyne interference. Moreover, a 5000-watt station might well expect to serve an area greater than 20 miles in radius, since it will normally produce a 1-mv per meter signal at 200 miles. In this case the interfering signal from the second station, now 2800 miles away, will be 0.073 mv per meter and the ratio 1000 to 73 or 13.7, which will give substantial crosstalk and a very bad heterodyne whistle unless the 25-cycle deviation limit is required. Even then the crosstalk and quality interference indicated would suggest that 5000-watt stations should not be assigned to the same channel within continental limits. Of course they would produce no crosstalk in their legitimate service areas during daylight or during nights of high absorption, but the services of both stations would suffer on good winter nights.

Such an analysis, however incomplete, serves to emphasize that the heterodyne interference problem is strictly a practical matter. Until one defines that character of broadcast service that he intends to protect from heterodyne interference, no rules can be formulated. Even then he must decide whether he wishes to preclude the possibility of beat interference at any time, whether he will permit occasional interference and protect average winter-night conditions, or whether he will merely arrange matters so that each station on a shared channel will reliably serve a small area immediately adjacent to its transmitting antenna. The practical station allocations as to power and separating distance will differ widely depending upon which end is intended. If it is desired to provide for the simultaneous operation of a large number of transmitting stations, so as to give outlets for the local features and activities of a large number of communities, the last-defined condition is the only one that can be met. Listeners not located within these small areas must then be served by powerful stations scattered over the country and each operating at night upon a cleared channel.

It may be interesting to conclude this analysis of heterodyne interference in the broadcast band by looking briefly at one of the channels as set up at this writing. Considering 570 kc, for instance we have the possibility of eight stations in simultaneous night-time operation, as follows:

1	WSYR	Syracuse, N. Y.	250 w, or
	WMAC	Cazenovia, N. Y.	250 w
2	WNYC	New York, N. Y.	500 w, or
	WMCA	New York, N. Y.	500 w
3	WSMK	Dayton, Ohio	200 w, or
	WKBN	Youngstown, Ohio	500 w

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4	WWNC	Asheville, N. C.	1000 w
5	KGKO	Wichita Falls, Tex.	250 w
6	WHA	Madison, Wis.	750 w, or
	WNAX	Yankton, S. D.	1000 w, or
	WPCC	Chicago, Ill.	500 w, or
	WIBO	Des Plaines, Ill.	1000 w
7	KUOM	Missoula, Mont.	500 w, or
	KXA	Seattle, Wash.	500 w
8	KMTR	Hollywood, Cal.	1000 w, or
	KPLA	Los Angeles, Cal.	1000 w

To study in detail the effects of each of these stations upon each of the others would be too extensive an undertaking for the present paper. We may, however, note the following conclusions based upon good average winter night-time transmission conditions:

WNYC and WMCA should produce a 1-mv per meter signal at 65 miles radius. A point on this circumference is only about 135 miles from WSYR, which station will deliver there a 0.34 mv per meter field. The ratio is about 3 to 1, and both crosstalk and severe heterodyne interference necessarily follow. A point on the same circumference, in the direction of WKBN, is about 330 miles from that station. WKBN should deliver to that point an average field of 0.19 mv per meter, giving a field intensity ratio of 5.2 to 1 as against the 100 to 1 that is needed to minimize interference. The interfering field from WWNC is 0.17 mv per meter and the ratio not quite 6 to 1. Even from KGKO the field is 0.032 mv per meter and the ratio therefore only 31 to 1. It is quite evident that few if any of the stations on this channel can ever attain their normal winter-time range, because of the limitations enforced by crosstalk and heterodyne interference.

All of this leads inevitably to the conclusion that the duplication of stations on any channel necessarily restricts the service area of each to the region immediately surrounding its transmitting antenna. In daylight, or at other times of high absorption, its signals will not travel far before falling below the noise level. At times of low absorption or low noise level (or both) the service area will be limited first by heterodyne interference and second by crosstalk. The areas served by each station, however, may be substantially increased if all are required to maintain their carrier frequencies with not more than 25 cycles deviation from the assigned frequency. Even then, however, a field ratio of 100 to 1 must mark the limit of the useful service zone.

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In the broadcast band, then, heterodyne interference may be eliminated or minimized by:

(a) Operating no more than one station at a time on each channel, within the continental United States and at night. This will permit service to reach remote or rural points.

(b) Operating more than one station on each channel, but requiring each to maintain its carrier frequency within 25 cycles of the assigned value. When such stations are located sufficiently far apart to avoid crosstalk between them, this will permit service to reach relatively limited areas immediately surrounding each station.

One other type of heterodyne interference should be mentioned. This is the occasional squeal or whistle of varying pitch that is heard when a radio wave of continuously changing frequency swings through the carrier being received. It is sometimes noted when a broadcast station tests "on the air," or when a neighbor using a type of radiating receiver allows it to oscillate strongly. Fortunately neither of these causes is much of a factor in broadcast reception today, so that we no longer concern ourselves with the desirability of legislating against the use of radiating broadcast receivers.

Outside the broadcast band one hears relatively little of heterodyne interference. The low-frequency waves from 10 to 60 kc or thereabouts, carrying long distance continuous wave telegraph and facsimile services, are under rigid control by those who use them. The various channels have been selected to avoid both crosstalk (if that word is permissible where telegraphy and not telephony is concerned) and heterodyne interference. The medium-distance waves from 60 to 120 kc are also telegraph waves in the main, and while not as definitely assigned to specific point to point services as those of lower frequency, are nevertheless used in such a way as to avoid beats between pairs of transmitters in simultaneous operation. The marine and other services using waves from 120 to 550 kc are relatively flexible, and, largely following the precedents of years of spark telegraphy, operate under conditions where interference may be expected at almost any time. The remedy here is usually either to change to another and temporarily unused frequency, or to wait until the interfering station is through sending.

The frequencies from 550 to 1500 kc, constituting the broadcast band, have already been considered in some detail. It is here that heterodyne interference is most prominent, because of the simultaneous operation for hour after hour of a large number of transmitting stations.

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In the vast high-frequency range above 1500 kc, which is rapidly coming into more and more extensive use, we should apply carefully the principles that have been taught by our experience in broadcasting. The strictest frequency stability requirements commensurate with the state of the art should be made, and duplicate station assignments to the same channel must be scrutinized with care if unnecessary interference is to be avoided. It is particularly important to keep clear the channels assigned to long-distance public radio telephony, to the various radio picture services being developed, and to relay broadcasting. All of these serve or will serve large numbers of people, and in none of them can the effect of interruptions be overcome by the simple expedient (so common in the telegraph services) of repeating a word or two.

Perhaps 90 per cent of the radio receivers now in use at frequencies above 1500 kc are capable of radiating substantial amounts of power, and consequently of disturbing reception at many points around them. The heterodyne interference produced by the improper use of such receivers may destroy long distance telephonic or telegraphic reception, may cast a blanketing pattern on the screen of a "television" receiver, or may spoil a musical program being rebroadcast to thousands of listeners. In the high-frequency spectrum, as has already been done in the broadcasting band, radiating receivers will have to be discarded. This, together with proper channel spacing, careful carrier frequency control and thoughtful geographical assignments of power and waves, will go far to prevent the development of heterodyne interference problems in this newest field of radio.

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AN OUTLINE OF THE RADIO INSPECTION SERVICE*

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Summary—*The purpose of this paper is to present a brief history of the Radio Inspection Service of the Department of Commerce from its inception July 1, 1911, up to and including the present day, together with an outline of the scope and general nature of the work performed by this important agency of the Government. The subject matter included in this paper may, therefore, be classified as historical and administrative, the latter including matters of engineering and law enforcement.*

HISTORICAL

THE Radio Inspection Service of the Department of Commerce was established and placed under the supervision of the Bureau of Navigation of the Department of Commerce and Labor[1] following the passage of the Wireless-Ship Act, approved June 24, 1910, to take effect on July 1, 1911.[2] Under this statute it was unlawful for any ocean-going steamer of the United States, or of any foreign country, carrying fifty or more persons, including passengers and crew, to leave or attempt to leave any port of the United States unless such steamer was equipped with an efficient apparatus for radio communication, in good working order, in charge of a person skilled in the use of such apparatus and that such apparatus was capable of transmitting and receiving messages over a distance of at least one hundred miles day or night. The statute further provided that the apparatus required shall not be deemed to be efficient unless the company installing it shall contract in writing to exchange, and shall, in fact, exchange, as far as may be physically practicable, to be determined by the master of the vessels, messages with shore or ship stations using other systems of radio communication; and, further, that the master or other person in charge of such a vessel which leaves or attempts to leave any port of the United States in violation of any of the provisions of this Act shall, upon conviction, be fined in a sum not more than $5,000 and any such fine shall be a lien on any such vessel, and such vessel may be libeled therefor in any district court of the

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[1] The Act of March 4, 1913, among other things changed the designation of the Department of Commerce and Labor to the "Department of Commerce" and the title of Secretary was changed to "Secretary of Commerce."

[2] An Act to require apparatus and operators for radio communication on certain ocean steamers, approved June 24, 1910.

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United States within the jurisdiction of which such vessel shall arrive or depart and the leaving or attempting to leave each and every port of the United States shall constitute a separate offense. The concluding section of the statute required the Secretary of Commerce and Labor to make such regulations as were necessary to secure the proper execution of the Act by Collectors of Customs and other officers of the government. The statute did not apply to vessels plying between ports less than two hundred miles apart.

The original plan called for the appointment of four Radio Inspectors for ship inspection work. The districts to be covered by these inspectors consisted, (1) New York and New England ports, (2) Atlantic ports from New York to Florida, (3) Gulf ports and (4) ports on the Pacific. Owing to the failure of Congress to authorize the full appropriation originally asked, it was possible only to appoint two Radio Inspectors.

The Inspectors appointed were Mr. W. D. Terrell of New York and Mr. R. Y. Cadmus of Bay City, Mich. They were selected from the classified Civil Service list on the basis of their experience in telegraphy, knowledge of electricity, wireless apparatus, and administrative ability. Following their appointment they were sent to the Bureau of Standards at Washington, D. C., for a short course of training in electricity and radio. Upon completion of their work at the Bureau of Standards, Inspector Terrell was assigned to duty at the port of New York, with jurisdiction over New York and New England ports, and Inspector Cadmus was assigned to duty at San Francisco, Calif., with jurisdiction over ports on the Pacific Coast.

The statutory duty of the Radio Inspectors was to examine and test the radio equipment on board all vessels, foreign and domestic, clearing from ports in the United States, subject to the Ship-Act, in order to determine, prior to vessels' clearance for sea, that the radio equipment was in good working order as required by law. It is of interest to note that the 1910 Wireless-Ship Act made no reference as regards wavelengths or call letters, nor were there any requirements regarding the licensing of the stations or the operators employed therein. The principal intent of the law was to provide safety of life at sea by requiring apparatus and operators on certain ocean steamers, also to prevent the use of apparatus incapable of intercommunicating with ship and shore stations employing other radio telegraph systems.[3] The Congress of the United States is the first legislative body to enact

[3] Statement of Admiral H. N. Manney, U.S.N., cited in publication entitled "Hearings Before Senate and House Committees in Connection with Radio Legislation." 1908–1913, p. 45, 46.

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a law on this important subject,[4] and the 1910 Wireless-Ship Act marks the formal recognition by the United States of radiotelegraphy as an indispensable agency for promoting safety of life at sea. It is generally recognized, however, that other nations were considerably in advance of the United States in other important essentials relating to the regulation of radio communications.

The first year of operation under authority of the 1910 Wireless-Ship Act clearly demonstrated the importance of the enactment, and on July 23, 1912, Section 1 of the 1910 Act was amended to take effect on October 1, 1912.[5] The amended Act made mandatory the providing of two or more operators skilled in the use of the radio apparatus, one or the other of whom shall be on duty at all times while the vessel was under way, an auxiliary power supply, independent of the vessel's main electric plant, capable of enabling the transmitting set to send messages over a distance of at least one hundred miles day and night, and the installation of an efficient communication system between the radio room and the bridge in good working order at all times. The amended act applied to vessels licensed to carry as well as those actually carrying 50 or more persons, including passengers or crew or both.

The equipment, operators, watches, and service in the case of vessels of United States registry were placed under the supreme authority of the master, and every wilful failure on the part of the master to enforce at sea the provisions of this Section rendered him subject to a penalty of $100.00. The amended Act so far as it relates to vessels navigating the waters of the Great Lakes went into effect on April 1, 1913, and on July 1, 1913 in the case of ocean going cargo vessels.

The next important radio legislation considered in the United States was the Berlin Radio Telegraph Convention.[6]

The Berlin Radio Telegraph Convention was the first International Radio Telegraph Convention to be signed by the United States. The membership of the Convention consisted of twenty-seven countries. The Convention contained twenty-three articles, the Supplementary Agreement three, Final Protocol seven, and there were forty-two Service Regulations.

It is a pleasing commentary that the Berlin Radio Telegraph Con-

[4] Annual Report of the Commissioner of Navigation, fiscal year 1910, Wireless Regulation, p. 28.

[5] An Act approved July 23, 1912, amending section 1 of an Act entitled "An act to require apparatus and operators for radio communication on certain ocean steamers," approved June 24, 1910.

[6] Berlin Radio Telegraph Convention, signed in Berlin on November 3, 1906, ratified by the Senate of the United States on April 3, 1912 and proclaimed by the President of the United States, May 25, 1912.

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vention,[7] proclaimed by the President of the United States on May 25, 1913, marks the formal recognition by the United States of radio communication as an indispensable agency of International Commerce.

The Berlin Convention continued in force until July 8, 1913, on which date the London International Radio Telegraphic Convention proclaimed by the President went into effect.

Following the adoption of the Berlin Radio Telegraph Convention the Congress of the United States passed an act to regulate radio communication.[8]

On August 13, 1912, the Congress of the United States passed a comprehensive radio law containing eleven sections and nineteen regulations. The sections contained the general substance of the law whereas the regulations, although having the force of law, were in the form of service instructions. The 1912 law continued in force until February 23, 1927, on which date the Congress of the United States passed a radio bill entitled "an act for the regulation of radio communications, and for other purposes."[9]

The next important radio legislation considered in the United States was the London International Radio Telegraphic Convention.[10]

The London International Radio Telegraphic Convention, proclaimed by the President July 8, 1913, was the second International Radio Telegraphic Convention to be signed by the United States. The membership of this convention consisted of forty-four countries including their possessions and protectorates. The Convention contained twenty-three articles, the Final Protocol three, and the Service Regulations affixed to the Convention contained fifty articles, the last five of which were cited under Miscellaneous Provisions.

The administration of the radio law embodied in the Acts of June 24, 1910, July 23, 1912, the act of August 13, 1912, repealed by the passage of the Radio Act of 1927, and the London International Radio Telegraphic Convention was lodged in the Bureau of Navigation of the Department of Commerce until February 26, 1927, on which date these activities were removed from under the jurisdiction of the Bureau of Navigation and placed under the immediate supervision of the Secretary of Commerce. Mr. Wm. D. Terrell, Chief Radio Supervisor, Bureau of Navigation, was placed in charge of the newly formed Division and given the title of Chief, Radio Division.

[7] A convention is a treaty concerning commercial rather than political matters. 12 A.L. and P. 6 Sect. 5.

[8] An act to regulate radio communication, approved August 13, 1912.

[9] The Radio Act of 1927.

[10] London International Radio Telegraphic Convention signed at London July 5, 1912, ratified by the Senate of the United States on January 22, 1913 and proclaimed by the President of the United States, and took effect July 8, 1913.

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The Radio Act of 1927 contained forty-one sections and represents the most extensive national legislation on the subject of radio to date. Under this Act five zones were established and five commissioners appointed, each a citizen of the United States and each a resident of a State within the zone from which he was appointed. The Commissioners were appointed by the President for terms ranging from two, three, four, five, and six years, respectively, from the date of the taking effect of the Act, with headquarters located in Washington, D. C.

Section 5 of the Act provided that from and after one year after the first meeting of the Commission, created by this Act, all the powers and authority vested in the Commission under the terms of this Act except as to the revocation of licenses shall be vested in and exercised by the Secretary of Commerce except that thereafter the Commission shall have power and jurisdiction to act upon and determine any and all matters brought before it under the terms of this Section.

For the purpose of this paper, time and space will not permit a full statement of the many involved matters set forth in the Radio Act of 1927. It is important, however, and mention is here made of the close relationship that exists between the Radio Division of the Department of Commerce and the Federal Radio Commission. The duties of both agencies are set forth in the law, and each have rather well defined duties. Yet, it is a difficult matter to determine in many instances just where the work of one leaves off and the other begins. The Radio Commission is not responsible to any executive officer, but rather reports direct to Congress. Its duties are both administrative and judicial, whereas the duties of the Radio Division are largely administrative, and as a general proposition the Division reports direct to the Secretary of Commerce, although there are certain matters which require it to report directly to the Federal Radio Commission. The Department of Commerce is directly charged with the enforcement of the Act of June 24, 1910, amended, to require apparatus and operators and the examination and licensing of radio operators. In addition to these duties, the Radio Division through its field inspection force makes regular inspections of radio stations ashore and afloat, and conducts investigations of the various forms of interference affecting the several radio services. The Radio Division from time to time makes investigations and inspections at the request of the Federal Radio Commission in addition to those which it makes regularly under its general authority. These inspections include both general inspections and inspections for licenses of the several classes of stations licensed by the Federal Radio Commission.

On March 28, 1928, Congress passed a law continuing the powers

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and authority of the Federal Radio Commission as conferred under Radio Act of 1927 until March 16, 1929.[11] The following other important changes were embodied in this act. Section 3 limits the license period of broadcasting stations to three months and all other classes of stations to a period not to exceed one year.

The second paragraph of Section 9 of the Radio Act of 1927 was amended to include an equality of radio broadcasting service both of transmission and reception. The amended Act also required an equal distribution of broadcast station licenses, bands of frequency or wavelengths, periods of operation and equal power to each zone by increasing or decreasing power when applications are made for licenses or renewals thereof, provided that if and when there is a lack of application from any zone for the proportionate share of licenses, wavelengths, time of operation of station power to which such zone is entitled, the licensing authority may issue licenses for the balance of the proportion not applied for from any zone, to applicants from other zones for a period of ninety days each, and shall specifically designate that said apportionment is only for said temporary period. Allocations shall be charged to the state, district, territory, or possessions wherein the studio and not the transmitter is located.

On March 4, 1929,[12] Congress continued the powers and authority of the Federal Radio Commission under the Radio Act of 1927, until December 31, 1929. Beyond extending the life of the Commission for the period herein cited the only other important change brought about under this Act was to the effect that the term of each member of the Commission shall expire on February 23, 1930, and thereafter Commissioners shall be appointed for terms of two, three, four, five, and six years, respectively, as provided in the Radio Act of 1927. The Act further authorized appointment of a general counsel at a salary of $10,000 per annum and assistant counselors not to exceed three, at a salary of $7,500 each per annum. The Commission is authorized under authority of the Act to appoint such other legal assistants as it may from time to time find necessary for the proper performance of its duties.

On October 4, 1927, the International Radio Telegraph Convention convened in Washington, D. C., and concluded its deliberations on November 25, 1927. At this Convention eighty nations were repre-

[11] An Act approved March 28, 1928, continued for one year powers and authority of the Federal Radio Commission under the radio Act of 1927, and for other purposes.

[12] An Act approved March 4, 1929, continuing the powers and authority of the Federal Radio Commission under the Radio Act of 1927, and for other purposes.

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sented, including their possessions and protectorates. It is of interest to note that the International Radio Telegraph Convention held in Washington in 1927 represented the largest gathering of foreign government and private radio interests assembled to date in the history of Government. The Convention contained twenty-four articles, thirty-four Service Regulations and seven supplementary regulations. The Convention was signed at Washington on November 25, 1927, ratified by the Senate on March 21, 1928, signed by the President on October 8, 1928, and proclaimed January 1, 1929.

It is a significant matter that before there were any laws promulgated for the control of world-wide radio communication it was realized by government and commercial engineers and others that the world in which we live from the standpoint of electrical communications, particularly radio, is a small place, and that radio communication constituted a means by which the nations of the world and vessels navigating the several oceans and other important waterways might be joined together as a single unit, thus bringing into general use a new instrumentality for the rendering of a great public service over land and sea. It is now evident from what has transpired in the field of international radio communication, both in an engineering and a legislative way, that the ideas expressed by the early investigators of this important subject were well founded.

It will be of interest, and mention is here made of the following radio conferences that were held during the years 1919 to 1929, none of which were subject to legislative enactment: the EU-F-GB-I Protocol held in Paris in 1919; the preliminary conference held in Washington in 1920, for drafting proposals and procedure for consideration at the Internation Radio Telegraph Conference to be held in Washington, 1925, which was postponed until 1927; the Inter-American Committee on Electrical Communications held in Mexico City in 1924; the 1925 agreement of the Government of the Unites States, Great Britain including Ireland, Canada and Newfoundland to prohibit vessels under their jurisdiction from using the 300-and 450-meter wave when within two hundred fifty miles of the coast line of the countries herein named.

Administration

For the purpose of facilitating the administration of the radio law and the engineering duties incumbent upon the Radio Inspection Service an increase in the personnel of the Inspection force was made and the following Radio Inspection Districts established:

District 1. Headquarters at Boston, Mass.: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut.

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District 2. Headquarters at New York, N. Y.: New York (county of New York, Staten Island, Long Island, and counties on the Hudson River to and including Schenectady, Albany, and Rennselaer) and New Jersey (counties of Bergen, Passaic, Essex, Union, Middlesex, Monmouth, Hudson, and Ocean).

District 3. Headquarters at Baltimore, Md.: New Jersey (all counties not included in second district), Pennsylvania (counties of Philadelphia, Delaware, all counties south of the Blue Mountains, and Franklin County), Delaware, Maryland, Virginia, District of Columbia.

District 4. Headquarters at Savannah, Ga.: North Carolina, South Carolina, Georgia, Florida, Porto Rico. (Headquarters now at Atlanta, Ga.)

District 5. Headquarters at New Orleans, La.: Alabama,[13] Mississippi, Louisiana, Texas, Tennessee*, Arkansas, Oklahoma, New Mexico.

District 6. Headquarters at San Francisco, Calif.: California, Hawaii, Nevada, Utah, Arizona.

District 7. Headquarters at Seattle, Wash.: Oregon, Washington, Alaska, Idaho, Montana, Wyoming.

District 8. Headquarters at Detroit, Mich.: New York (all counties not included in second district), Pennsylvania (all counties not included in third district), West Virginia, Ohio, Michigan (lower peninsula).

District 9. Headquarters at Chicago, Ill.: Indiana, Illinois, Wisconsin, Michigan (upper peninsula), Minnesota, Kentucky, Missouri, Kansas, Colorado, Iowa, Nebraska, South Dakota, North Dakota.

Engineering

Radio communication has developed so rapidly during recent years that time and space will not permit of a full statement of the multiplicity of technical problems involved in the work of the radio inspection force.

Following the establishment of the radio inspection service and for several years thereafter, the technical problems consisted largely of those relating to the inspection, testing, and adjustment of the several types of spark transmitters and associated apparatus; the latter comprising of the generating plant for supplying electricity to the motor generator which forms an essential part of the primary circuit of the radio transmitter; the storage battery emergency power sypply; charging circuits and the measuring instruments for determining

[13] States of Alabama and Tennessee now in Fourth Radio Inspection District.

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the values of voltage, current, and power. In addition, the inspectors were required to examine and test the several types of receiving sets then in use. The receiving apparatus was of a rather simple type and employed principally crystal detectors. Wavemeters were employed for adjusting the transmitting apparatus to the several wavelengths then in use. Following the inception and use of the wavemeter which comprised a simple circuit, Fred A. Kolster, physicist, employed at the Bureau of Standards, invented an instrument later known as a Kolster decremeter.[14] This instrument was both a wavemeter and a decremeter, and was considered one of the most important radio inventions at that time. This instrument not only enabled the wavelength value of a transmitter or a receiver to be determined, but also served to measure the pureness and sharpness of the emitted wave. This instrument served a very useful purpose and is still employed for measuring damp wave emissions.

In addition to the inspection of commercial radiotelegraph stations ashore and afloat, the inspection force was required to inspect and test a large number of experimental radiotelegraph stations engaged in development and research and privately owned stations, the latter known as amateur stations. The inspections were made for the purpose of preventing interference and to insure compliance with the radio laws in other particulars. The 1912 law among other things required both station and operator licenses, the work of inspecting radio stations, ashore and afloat, for the several classes of licenses was an additional duty incumbent upon the radio inspection force.

The examination of applicants for the several classes of operator licenses was largely performed by the field inspection force. This work included the preparation of the examination questions, the conducting of the examinations, rating of papers and issuance of licenses to the successful candidates. Operator licenses were issued for a period of two years, therefore it was necessary to issue renewal licenses to operators having the necessary service for renewals at the end of that period.

As time went on, the radio art developed rapidly; radio stations and services increased in number and in kind. In addition to the spark transmitting stations, arc and high-frequency alternator transmitting stations came into considerable use ranging in power from 2 to 200 kw. As the arc and high-frequency alternator were radiators of continuous wave signals it was necessary to develop receivers that would efficiently respond to such signals, hence the vacuum-tube receiver came into quite general use.

[14] F. A. Kolster, "Direct reading instrument for measuring logarithmic decrement and wave length of electro-magnetic waves," Bureau of Standards Scientific Paper 235, 1914.

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Regulation 15 of the 1912 law restricted private stations, i.e., amateur stations both as to power and wavelength. The power was limited to 1000 watts with wavelengths not to exceed 200 meters. In the course of a few years the amateurs developed a very efficient communication system which later became national and international in scope. The radio industry owes considerable to the American amateur for the pioneer work done in the field of high frequency, long distance, telephone and telegraph communication.

The radio art continued to develop and expand, and in 1921 the first commercial radio telephone broadcasting station was established and licensed. Subsequent to 1921 stations of this class have increased in number to some six hundred stations, and the service furnished by this class of station numbers among the most important in the field of radio communication. Following radio telephone broadcasting, photo radio was developed on a commercial basis, and service is now being carried on between the United States and Europe. Television was next in line, although at this writing the work is largely experimental. High-frequency radiotelephone broadcasting and radio beacon stations on land for furnishing bearings to ships at sea and to aeroplanes moving over land have come into general use, as has the beacon receiver for ship and aeroplane use. At this time important experiments are under way in connection with the development of radio beacon transmitters for the mobile stations.

In 1927 radiotelephone service was established on a commercial basis between the United States and England, which service has since been extended to the principal countries in Europe. The several radio services herein cited have, as in the case of others, greatly increased the technical work of the radio inspection service. It is generally recognized by engineers and others that there are definite engineering limitations on the use and expansion of radio. It is, therefore, essential that the most careful consideration be given to the development of this new instrumentality of commerce. In order to deal adequately with radio problems, so far as it concerns the radio inspection service, the Department of Commerce has considerably increased its field force. In addition to the main offices of the field inspection service, suboffices have been opened in Philadelphia, Pa., Buffalo, N. Y., Kansas City, Mo., Duluth, Minn. (in the summer), St. Paul, Minn. (in the winter), and Los Angeles, Calif. There has been for several years a suboffice located at Norfolk, Va.

In order to deal effectively with the engineering work of the field inspection force, the Department of Commerce has purchased and now has in operation six radio test cars. Each test car represents

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a complete mobile radio laboratory and is equipped with apparatus for measuring the operating frequency of broadcasting stations, field intensities from which field contour maps are made, secondary standards of frequency for calibrating frequency meters and complete equipment for conducting radio operators' examinations. The receiving system installed on the test cars covers a wide range of frequencies and may be operated independently for use in connection with the study of directional reception and numerous other problems involved in the study of reception from the several classes of radio transmitting stations in operation. The test cars represent the latest addition to the equipment already supplied the main and sub-offices of the field inspection force. At this writing, deliveries are about to be made of secondary standards of frequencies for use in the field offices. This equipment represents the most modern of its kind developed today and includes receivers designed with a high degree of sensitivity and selectivity and covers the entire frequency band employed in the field of radio communication at the present time.

The Department of Commerce, Radio Division, has plans under way for the installation of a Constant Frequency Monitoring Station to be located near Grand Island in the state of Nebraska. It is expected this station will be completed in the late Fall of this year (1929). At this writing it is too early in the proceedings to go into the matter of the construction and operation of this station; however, it is hoped that it will furnish interesting material for a future paper in the PROCEEDINGS.

LAW ENFORCEMENT

A fundamental rule of the American Constitutional System fixes the principle that the governmental powers are divided into there departments, namely, the Executive, the Legislative, and the Judicial.

The enforcement of the Radio Communication Laws of the United States and the International Radio Telegraph Convention[15] is vested in two governmental agencies, the Federal Radio Commission and the Department of Commerce. The titles of the statutory Acts of Congress and the International Radio Telegraph Convention, enforced by the Federal Radio Commission and the Department of Commerce are as follows: An Act approved July 23, 1912, amending Section 1 of an act entitled "An Act to Require Apparatus and Operators for Radio Communication on Certain Ocean Steamers" approved June 24, 1910, the Radio Act of 1927, approved February 23, 1927, and the International Radio Telegraph Convention, and general and supplementary

[15] See United States Constitution; Art. VI, Section 2. See U.S. Constitution; Art. II, Section 2, Paragraph 2. 14 A. L. and P., 20, Section 22.

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regulations relating thereto, ratified by the Senate on March 21, 1928, effective January 1, 1929.

The 1910 Wireless-Ship Act is enforced by the Department of Commerce, whereas the Radio Act of 1927 and the International Radio Telegraph Convention are enforced jointly by the Federal Radio Commission and the Department of Commerce. Under the existing arrangement the Department of Commerce enforces the law in the field, whereas the Federal Radio Commission enforces the law from its headquarters at Washington, D. C. As previously stated, there is a joint responsibility in the matter of law enforcement and full cooperation is maintained at all times between the Federal Radio Commission and the Department of Commerce.

Section 4, Paragraph f, of the Radio Act of 1927, authorizes the Federal Radio Commission and the Department of Commerce to make such regulations as may be necessary for the proper execution of the Act. These regulations must not be inconsistent with the law and shall only consist of such regulations as have to do with regulating the mode of procedure for carrying out the intent of the law.

Appendix

Federal Radio Commission Zones Established Under Section 2 of the Radio Act of 1927

Zone 1 includes the states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Delaware, Maryland, the District of Columbia, Porto Rico, and the Virgin Islands.

Zone 2 includes the states of Pennsylvania, Virginia, West Virginia, Ohio, Michigan, and Kentucky.

Zone 3 includes the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Mississippi, Arkansas, Louisiana, Texas, and Oklahoma.

Zone 4 includes the states of Indiana, Illinois, Wisconsin, Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Missouri.

Zone 5 includes the states of Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, the territory of Hawaii, and Alaska.

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Proceedings of the Institute of Radio Engineers
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THE PROBLEMS CENTERING ABOUT THE MEASUREMENT OF FIELD INTENSITY*

BY
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Summary—*A brief recount of some of the major contributions to radio field intensity measurement work is given, showing that these represent a great deal of the groundwork on which future developments will be based. The general problems of this sort of measurement work are discussed, as well as the equipment with which the Radio Division of the Department of Commerce expects to handle them. Typical illustrations of radio transmission in cities are given, showing the necessity and importance of field intensity surveys in the location of radio stations. The prediction is made that the time will come when all radio broadcast transmitters of 1 kw or more power will be located on the basis of radio field intensity surveys.*

An examination of the strictly technical aspects of radio transmission developments during the past year discloses some very interesting and highly important applications of radio field intensity measurements. While the industry has not yet by any means taken full advantage of radio field intensity measurements and surveys, nevertheless there is a very definite trend toward the more complete utilization of the subject as applied to transmitter design and location.

Like every other engineering project there must be laid down a groundwork of fundamental principles before practical applications may be made, and in the case of radio field intensities that groundwork which we have is of comparatively recent origin. In passing it is proper that some of the more important developments be recounted. Among the leaders in the broader aspects of the subject stand the works of Dr. L. W. Austin, which have frequently appeared in the PROCEEDINGS of the Institute, as well as in other publications. In line with these we also have the work of G. W. Pickard similarly published. Beside these developments stand those of Bown, Martin and Gillett presented in the PROCEEDINGS under the title of "Distribution of Radio Waves from Broadcasting Stations in the City Area." Dr. A. N. Goldsmith's article entitled "Reduction of Interference in Broadcast Reception" appeared also in the PROCEEDINGS, and L. Espenschied's article entitled "Radio Broadcast Coverage in City Areas" appeared in the *Journal* of the American Institute of Electrical Engineers. The paper entitled "Some Studies in Radio

* Dewey decimal classification: R270. Original manuscript received by the Institute, April 5, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

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Broadcast Transmissions" by Ralph Bown, DeLoss K. Martin and Ralph K. Potter, also appeared in the PROCEEDINGS of the Institute.

Several other articles in these PROCEEDINGS as well as some appearing in other journals have furnished certain avenues of approach toward the more complete utilization of the possibilities of radio field intensity measurement work, and from them many conclusions were drawn which have now become principles in the industry. Noteworthy among them is the acceptance of the 10-millivolt-per-meter level as essential to good broadcasting service, and the rating of service areas in terms of miles for various powers of transmitters which this figure permits.

In harmony with these principles there have been undertaken during the past year several surveys having for their objective the locations of radio transmitters. A great deal of development work on transmitters has accrued directly as a result of these efforts. The beneficial results of surveys of the fields of transmitters are felt very strongly on several of the latest high-power broadcast installations. The measurement of electric fields permits not only the primary determination of a given station's location, but also a complete analysis of its radiating mechanism and it is upon these two main factors that a transmitter works to its greatest advantage.

In addition to the great value of field intensity work in the broadcast spectrum, projects of considerable magnitude are now under way, and have been for some time, with respect to radio communication between aircraft and ground stations, not only for the exchange of intelligence but also for direction-finding purposes.

The high frequencies present a fertile field for field strength measurements, especially when an examination is made of the methods by which the short-wave channels are being exploited by the nations of the world since the International Radio Telegraph Convention held at Washington, D. C. in 1927. It will be recalled that the various nations are entitled to use certain channels which may only be used by other nations provided no interference results. Under these circumstances one of the most valuable sources of information must certainly be radio field intensity measurements.

Most of these things as outlined are apparent to anyone in the industry, and have been so for some time. With the realization of the necessity of meeting these problems, the Radio Division of the Department of Commerce prepared in 1925 to determine in what way they could best be attacked. As a result it had developed especially for its use a radio field intensity measuring set in keeping with latest known practices in the art. An illustration of one of these sets is shown in Fig. 1. The fundamental principles of operation of this

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equipment were presented in a paper already published.[1] This set is capable of operating over the frequency range of 6000 to 200 kc per sec. and responds satisfactorily over a signal level range of from 10 μ v per meter to about 4 v per meter.

The general requirements for such a device are very severe inasmuch as it must by nature be a delicate piece of equipment and yet must, at the same time, be portable. By portable is meant a permanent mounting in an automobile under conditions of travel over all kinds of roads at all speeds. Further than this, the set must be completely self-calibrating, must be fast in operation, and must be capable of extreme accuracy where it is to be used as an instrument for law enforcing purposes. The overall accuracy of the equipment is guaranteed to be correct to plus or minus 5 per cent. At the same time the equipment must be free and independent of the human element so that uniform results are always obtainable. The first of these sets has been in operation for considerably more than a year, and has met these requirements.

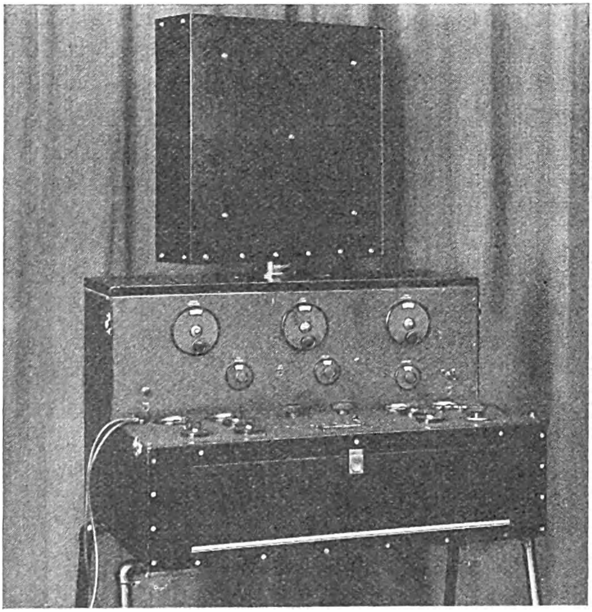

Fig. 1—Radio Field Intensity Measuring Set.

As a result, the Radio Division has now purchased and has in operation six of these equipments, and will shortly secure enough

[1] H. T. Friis and E. Bruce, "A Radio Field Strength Measuring System for Frequencies up to Forty Megacycles," Proc. I.R.E., 14, 507; August, 1926.

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additional similar equipments to supply each of the nine radio districts.

These sets are mounted in automobiles having bodies of special design. Fig. 2 is an illustration of two of these cars, of which there are six now in service.

With this equipment it is planned ultimately to survey the field of every radio broadcast transmitter in the United States as well as to conduct measurements on the high-frequency channels and other services. To date twelve complete surveys have been made in the broadcast band. This work has been done on both coasts and in the north and south parts of the country. Some of the work has been published.[2]

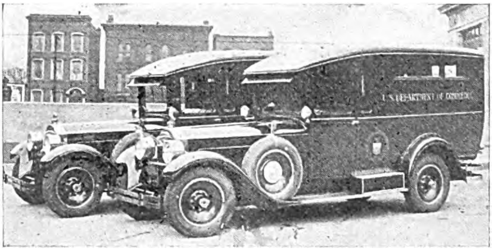

Fig. 2—Cars in Which Are Permanently Mounted Radio Field Intensity Measuring Sets Developed for Radio Division of the Department of Commerce.

In addition to field survey work, the field strength sets are expected to be used for law enforcement purposes such as the detection of increase of power at stations not authorized to do so. With a field strength measuring set and certain predetermined data at hand it is possible to check any change in power at a station and thus determine how much this change is without going inside the station. This has been done in several instances.

Progress was necessarily slow at first, but is gradually assuming greater proportion. This was so of necessity, inasmuch as a great deal of experimental work had to be done before a unified system of operation for all of the equipments could be developed. First in the order of development was the radial system of measurement. In making a survey by this method, radial directions are taken from the transmitter which becomes a center, and measurements are made at inter-

[2] S. W. Edwards and J. E. Brown, "The Use of Radio Field Intensities as a Means of Rating the Outputs of Radio Transmitters," Proc. I.R.E., 16, 1173; September, 1928. Other material by the same authors was published in Radio Service Bulletin, March, 1927.

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vals on each of them. At least ten radials should be chosen for powers on the order of 1 kw, and perhaps more for higher outputs. The measurements are made at 0.3 mile intervals in urban localities and less frequently in suburban and country locations, the measurements to start within a few wavelengths distance of the station and continue on until at least the 5-millivolt-per-meter signal level has been reached. Much practical experience must be gained before successful measurement work can be done, due to the difficulties of securing true signal readings in cities where there are always a multiplicity of wire circuits, steel buildings, and other metallic objects. Methods had to be developed by which accurate determination of the effects of any of these things on the signal level could be noted. By a happy circumstance it was found that a false reading of signal level is almost always accompanied by either an untrue radio compass bearing on the station being measured, or by a very poor minimum signal from the station when the loop or signal collector is rotated. In other words, it has been found that any object capable of causing distortion of the wave front of the advancing wave form very likely also affects its signal voltage level. The immediate result of this finding was the requirement that on the field strength sets used, the loop must be capable of giving a good minimum signal at all frequencies.

Since the surveys are being made in all parts of the country by different men, a standard system of depicting the results of the surveys had to be developed. In doing this certain practises used in topographical work were borrowed and put into use. As an example, after all of the radical directions have been measured, curves are made plotting the measured values of signals against their respective distances in miles; these curves show the variation in signal strength with distance. From these curves may now be taken the significant values of field strengths which are located in their proper places on an accurate map of the locality under survey. Emphasis is usually placed on those values of signals in multiples of ten; that is, lines of strength of, say 100, 90, 80, etc., millivolts per meter are drawn terminating in the lowest value measured, which may be either 1 or 5 millivolts per meter. In special instances this order may not hold but these are generally of rare occurrence. Where instances of this kind develop, they are usually in the nature of a rapid determination of the general nature of the station's field. The procedure is then to determine where the high signal or possible interference level lies and where is the outer border of its good service area. Suggested values may be perhaps 100 millivolts per meter, interference level, and 10 millivolts per meter to 5 millivolts per meter as the minimum good service level. By inter-

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ference level, in this case, is meant that signal level from a station which is so high as to make difficult the reception of other stations on different and considerably removed frequencies.

In addition to the regular points at which measurements are made for the survey, several places are selected at which signal voltage readings are taken for purposes of antenna analysis. These points are carefully selected near the station and are used for calculation purposes in determining the effective height of the transmitting antenna, its radiation resistance, and its radiated power. These points are selected with great caution to make sure that true readings are obtained which are not greatly attenuated.

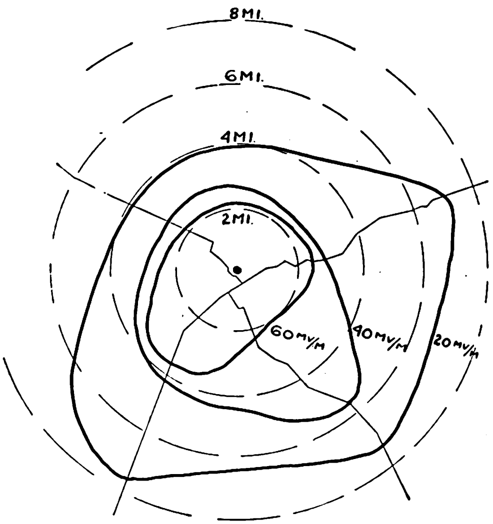

Fig. 3—Field Intensity Contour Maps of 1-kw, 720-kc Broadcasting Station. Antenna I, 7.2 amperes; effective height, 41.7 meters.

The general problem of radio transmission is at best a highly complex proposition, and when a station is located in a city of some size the results which will be obtained very nearly defy prediction. While all cities exert much the same effects on transmission, the general efficiency of transmission in a city is almost entirely a matter of the frequency used. There are shown, herewith, two recent radio field intensity contour maps made on two different broadcast stations operating in the city. Fig. 3 is the field intensity contour of a 1-kw station power, operating on a frequency of 720 kc; Fig. 4 is the field intensity contour of a 5-kw station, operating on a frequency of 640 kc. Both stations are of the latest design, well erected and are located on steel buildings approximately six stories high. The stations are approxi-

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mately 1/2 mile apart and have the same type of surrounding buildings, street car lines, etc. In other words, except for the frequencies and the power used, the stations are nearly identical, and yet the transmission characteristics are quite widely different, though there is a frequency difference of only 80 kc.

Signals from both stations are seriously attenuated in a southwesterly direct, and but for this attenuation the station in Fig. 4 would have a very good field. An examination of the field of the station in Fig. 3 shows some irregularities in other directions; whether this indicates heavy attenuation in these particular localities for frequencies in

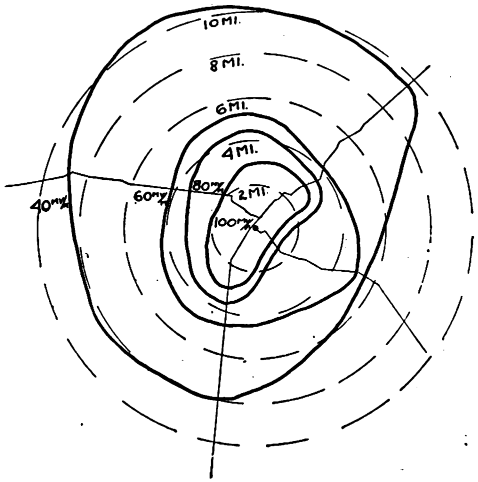

Fig. 4—Field Intensity Contour Maps of 5-kw, 640-kc Broadcasting Station. Antenna I, 20 amperes; effective height, 29.7 meters.

the region of 720 kc, or whether there is a steady increase in attenuation with increase in frequency, is not known.

The above examples are very good for demonstration purposes, and they indicate beyond all doubt the enormous handicap under which signals in the broadcast band radiate under the very erratic conditions of city attenuation. They tend to show the value of field intensity measurements in the location of radio transmitters. A glance at both Figs. 3 and 4 indicates that the severe attenuation in the southwest direction holds for both cases. Were a station to be located in the locality described, and in the range of frequencies under consideration, one of the most important features would be to place it so that the poor transmission caused by the southwest section of the city would fall in the direction of the minimum number of listeners. Very fortunately

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for the station under discussion, transmission in a southwesterly direction is of no great importance since few broadcast listeners reside in this direction for several hundred miles. In passing, it might be said that this severe attenuation is caused by a very dense system of electric power lines and railroads with their associated wire circuits. The section itself is the manufacturing part of the city, and although reasonably well localized to one area is rather large in size.

It is expected that by means of all of the field strength sets in operation by the Radio Division a great deal of valuable information will be uncovered. This information will not only be of value to the radio station owner but, if he cares of avail himself of it, will certainly become beneficial to the radio listener. At the present state of the art we are going through a remarkable stage of improvement. The value of higher power in broadcasting is being recognized, and through it the public is enjoying better service. The advent of high percentage modulation is being noticed, and its effect seems to be such that we may have to reduce our standard signal level of 10 millivolts per meter to some lower value, perhaps 5 millivolts per meter or even lower. Under any conditions, the combination of high percentage modulation, high power, and intelligent location of stations through field intensity measurement work is certainly going to usher in a period of broadcasting service superior to anything we have ever had before. The guess is ventured that in the near future no station of 5 kw or more power, and very likely less, will be located without at least some consideration of the field which it should produce for best satisfaction. The Radio Division of the Department of Commerce hopes to assist and expedite the use of radio field intensity measurement work in all of its phases, and believes that steps in this direction are in the line of progress and are of value to the public and to the radio industry in general.

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THE RADIO ENGINEER'S RESPONSIBILITY IN COPING WITH MAN-MADE INTERFERENCE*

By
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MAN-MADE interference is growing in its relative importance as an obstacle to the service value of broadcast reception. Quality of transmission, studio design and management, selectivity of receivers, and quality of reproduction have been progressively improved by the application of sound engineering principles, leaving the suppression of man-made interference as one of the major obstacles to undisturbed reception. Its elimination has been considered largely an operating or field problem for individual elimination in outstanding cases where radio reception by large groups of people has been interfered with. We have been content to let the man-made interference wait for attention until after it is created rather than preventing it in advance by the application of proper engineering design before it arises.

It would be repetition to enumerate the various means used to eliminate electrical interference in connection with electrical appliances, motors, dynamos, and industrial machinery. The power companies under the guidance of the National Electric Light Association have made marked strides in developing methods for outside plant and in distributing information on how to locate power system leaks with reasonable celerity. Most of the power networks are being erected with full appreciation of the power company's responsibilities to the listening radio public. Insulation and testing methods have improved steadily, so that the few instances of serious complaint are distinct evidence of a non-cooperative attitude on the part of the power company rather than the existence of a problem technically difficult of solution.

If we are to make substantial progress in eliminating all important causes of electrical interference, however, the problem cannot be left to the power companies alone, although they have naturally taken the leadership up to this time. The finger of public condemnation is too readily pointed at them when electrical interference is experienced, even though they are not, in the majority of cases, directly responsible for complaints. Investigation has shown that household equipment

* Dewey decimal classification: R170. Original manuscript received by the Institute, February 20, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

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is a very frequent cause of interference in residential districts. Such equipment frequently sets up radio-frequency impulses which are released as electro-magnetic waves from power networks, and are also distributed through the power conductors into the radio receivers connected with them. Household equipment is usually used only spasmodically, making it most difficult to identify it as the cause of noisy radio reception by the standard methods of interference determination. Often simple devices used in residential areas, such as vacuum cleaners, fans, electric refrigerators, oil burners, cash registers, and medical equipment interfere only momentarily but none the less annoyingly with reception over an area of several square miles. Such interference once located is not difficult to suppress, and the methods are well known. However, it seems well nigh hopeless to expect ideal reception conditions by searching out millions of isolated and individual cases of electrical disturbance. As long as electrical equipment is manufactured without consideration of its radiating properties, interference will continue to affect home radio reception, unless radio receivers of a much lower order of sensitivity are employed.

Radio engineers have recognized this problem and have attempted to render the radio receiver less sensitive to the influences of power line fluctuations by using chokes to suppress them and incorporating adequate shielding and by-passing of radio and audio-frequency circuits with a view to disassociating these circuits as far as possible from the power circuits. The existence of bypass condensers and protective chokes in the receiver is at least psychological recognition of an obligation to cope with disturbances introduced through the power circuit although, in some instances, it must be said that the designer has little more than this in mind. That there is a considerable variation in the effectiveness of the by-passing and choking employed can be demonstrated readily by comparing the noise at a given point upon several different makes of commercial receivers. I would like to consider man-made interference in a somewhat broader way with a view to determining, if possible, the trends of both electrical appliance and radio receiver design and development as they affect this problem.

Each time an electrical circuit is made or broken or a rapid change in load on a power circuit occurs, radio-frequency impulses are set up and radiated from the power network. Two broad courses are open for the control of such interference; the choice depends upon the activity of the radio engineer. These two courses are (1) altered balance of the broadcast transmission and reception system so that less responsive receivers are required, or (2) "radiation-proofing" of electrical equipment.

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Although there has been a tendency toward increased power in broadcasting, we have hardly reached the threshold of development in this direction. It is quite within the scope of the engineer's imagination to visualize ultimately a broadcasting system comprising transmitters of a million watt power. Compared with other systems in daily use this is by no means a large unit; the power bill for such a broadcasting station might run from fifty to one hundred dollars an hour. We use several hundred times that power in transporting week-end excursionists to a single metropolitan bathing beach, and certainly radio broadcasting is of at least comparable importance in our daily lives. While a million watts represent a substantial increase in the power of broadcasting, such power need not be feared as a dangerous monster.

A system of broadcasting with transmitters of this order of power would require somewhat altered receiver design. Obviously we would employ less sensitive receivers, and instead of an exposed aerial system we would use an adjustable pickup means shielded from incoming impulses to a degree determined by the field strength of the nearest broadcasting station. Stations of such power could serve the centers of population with antennas located at some distance from congested centers. It is quite conceivable that receiver development could keep pace with progressively increased powers of the order suggested.

Allocations of wavelengths under these conditions would be simplified because the high grade service range of such stations might well be as much as five hundred miles. Ninety such stations spread geographically over the country would give ten or twelve program choices at any point, and may be compared with present conditions where perhaps less than 40 per cent of the area of the country is within the wide high grade service range of *any* broadcasting station. Furthermore, the initial and maintenance cost of receivers would be lessened, and quality of reproduction improved, with the consequent result that the radio listening public would be enormously increased. This in turn would have a healthy effect on the economic position of the broadcaster.

But such a system of broadcasting would also be considerably more costly than the present annual maintenance expense of approximately thirty or thirty-five million dollars. It might cost one hundred fifty million to two hundred million a year or more to maintain ninety stations of this order of power.

The entire burden of overcoming man-made interference, should developments proceed entirely in this direction, would be placed upon the radio industry.

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The other method of attacking the elimination of electrical interference is by cooperating with other branches of the electrical industry. The power companies, one of the most important groups to be considered, can be expected to do their part because their relations with the public would not permit them to stand for any length of time in the position of prime responsibility for interfering with radio reception. We may, therefore, expect progressive improvement in power plant and network design and equipment which will reduce to a minimum electrical interference originating in faulty installation, high resistance, grounding of power lines, and the other well known causes which lie in that field. We may also expect industrial inspection looking toward the elimination of interference resulting from high power electrical machinery, smoke precipitators, electric welding equipment, and similar interference creating devices.

The real difficulty lies in the modernization of household equipment such as electric fans, oil burners, cash registers, electric refrigerators, vacuum cleaners, and violet ray machines. All of these must be designed with elimination of radio interference in mind. It is difficult to estimate the cost to the electrical industry of the necessary modification of such devices to accomplish this objective, but as nearly as can be estimated, the equipment of all vacuum cleaners, washing and ironing machines, oil burners, and sewing machines with chokes and filters so that they can be operated from the same power circuit as a radio receiver of the sensitivity at present used without noticeable interference would have cost the electrical industry ten million dollars for 1928.

Unquestionably, the most economical approach to the solution of this problem lies in eliminating electrical interference at this source rather than over-riding it where its effect is felt. But to thrust the responsibility of silencing electrical equipment upon an industry disassociated from radio is to impose a task of no small magnitude. No progress whatever has been made in fixing the responsibility for radio silence upon the makers of interference creating equipment. Only in isolated instances is the influence of minor electrical equipment considered a problem for any but the radio industry to solve. The radio engineer must exert his influence in electrical standardization. Instead of viewing the electrical industry as competitive and disassociated he must work hand in hand with the appliance, power, and traction industries. The radio engineer through his engineering association's standards committees and through the manufacturers' standardization groups must clearly voice his opinions or he will find eventually that the entire burden of eliminating the effect of electrical

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interference will necessarily be lodged with the radio receiver itself and the transmitting system which furnishes it with programs, at a cost to the radio industry which I have endeavored to indicate.

A closely allied problem which I cannot refrain from mentioning at this time is that of the importance of power line voltage regulation. Power radio receivers must now be designed to operate on almost any voltage between 105 and 120 volts. Prior to the appearance of the radio receiver, voltage variations from five to eight per cent have had but little effect in the operation of home equipment. But the sensitivity and selectivity of most power operated radio receivers and the life and efficiency of practically every vacuum tube is closely dependent upon the supply of correct line voltages to the power system of the radio receiver. In order to cope with varying conditions adjustment is frequently provided so that the average line voltage conditions may be compensated for. But these means do not meet the diurnal fluctuations frequently encountered, for example, when the industrial load is discontinued at the end of the working day. It cannot be left to the owner of the radio receiver to make constant readjustment of his receiver at different hours of the day and night, and the only practical solution lies in the standardization and stabilization of power line voltage supply. Here again the radio engineer could profitably exert his influence in the councils of the electrical industry on a basis of cooperation rather than with the competitive and isolated point of view toward which he now inclines. The obligation for the cure of both fluctuations in power line regulation and electrical interference is sufficiently debatable that the radio industry cannot afford to overlook any opportunity to secure the friendly cooperation of the electrical industry with a view to solving these difficulties in the most efficient and economic manner. This is a responsibility of the radio enginer and the radio industry which must be promptly assumed. Little progress has been made in this direction up to this time. Failure to assume the responsibility may prove a serious burden to the industry which may ultimately reach large proportions.

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RADIO COORDINATION*

BY
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THE elimination of radio interference is a problem of community coordination. To legislate against the occurrence of interference will accomplish as much and be as sensible as to legislate, for instance, against the occurrence of lightning. Although the actual tracing down and elimination of a specific disturbance may require the services of a specialist, the greatest advances in the highly technical art of locating and eliminating interference will be valueless without complete community interest. For progress in the betterment of radio reception conditions, continued cooperation of manufacturers, newspapers, amateur radio and broadcast listeners' associations, dealers, electric supply utilities, communication utilities, municipalities, electric railways, and perhaps most important of all, "the man in the street," must be obtained.

The problem of interference, at least insofar as it refers to interference with individual or family activities or obligations, is as old as civilization; the expression "a man's house is his castle" is nothing more nor less than a guarantee, not of individual freedom as such, but of prevention of interference. The problem of interference between services to the public is at least as old as the so-called Industrial Revolution; in 1857 Abraham Lincoln before the United States Circuit Court at Chicago argued and won a case of interference which concerned the placing of a railroad bridge across the Mississippi River.[1] The bridge undoubtedly interfered somewhat with river traffic, at that time of immeasurable service to the public, but the same general public also required the additional services to be rendered by the railroads. The problem of interference between the facilities of the electric supply and communication companies has long been recognized, and literally thousands of articles have been written on this subject,[2] which is closely akin to that of radio interference. The first and foremost principle under which two of these great industries

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[1] F. F. Fowle, "A Famous Interference Case," The N.E.L.A. Bulletin, October, 1927.

[2] Bibliography on Inductive Coordination, The American Committee on Inductive Coordination, New York, 1925.

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exist together today in every section of the country merits quotation:[3]

> "Duty of Coordination.
>
> "(a) In order to meet the reasonable service needs of the public, all supply and signal circuits with their associated apparatus should be located, constructed, operated and maintained in conformity with general coordinated methods which maintain due regard to the prevention of interference with the rendering of either service. These methods should include limiting the inductive influence of the supply circuits or the inductive susceptiveness of the signal circuits or the inductive coupling between circuits or a combination of these, in the most convenient and economical manner.
>
> "(b) Where general coordinated methods will be insufficient, such specific coordinated methods suited to the situation should be applied to the systems of either or both kinds as will most conveniently and economically prevent interference, the methods to be based on the knowledge of the art."

The policy expressed needs no comment.

The harnessing of electricity by man for his peculiar purposes does not prevent it from being a phenomenon of nature. Individual men die; specific dielectrics decay. No power on earth can prevent a condenser in a radio receiver from going bad eventually. Nor can any human power prevent electrical insulation from eventually wearing out. In either case occurs the so-called "man-made interference." The problem of the elimination, or, more properly, the reduction of this interference, cannot be solved by regulation or legislation. It is quite conceivable that in some cases the best engineering solution of an interference case is to let it keep on interfering. It may well be in an imaginable case that the community is best served by suffering from some source of interference provided it receives some greater service in return. The interferer is not necessarily always in the wrong. Judge Davis for instance says:[4]

> "The characteristic feature of the [radio interference] situation presents a conflict between individuals, each of whom is carrying on a legitimate activity. It is not a case of an obvious wrongdoer performing an act denounced by law, custom, or good morals to the injury of his neighbor. The person causing the interference, whether he is engaged in radio communication or is using some electrical device for a noncommunication purpose is in a lawful business within his inherent rights. He is using his own property for his own lawful purposes. The person using his property for radio communication and suffering the disturbance, whether on the sending or receiving end, is equally within his rights and his acts are legal and proper."

The most modern thought, however, seems to be that the public is entitled to the best coordinated service from all sources that it is possible, from an engineering standpoint, to provide. It is thus part of the neighborly duty of each of us, no matter whether we operate an interfering violet ray machine or high-frequency laboratory, and no

[3] Reports of Joint General Committee of National Electric Light Association and Bell Telephone System on Physical Relations between Electrical Supply and Signal Systems. Edition of December 9, 1922.

[4] "The Law of Radio," S. B. Davis; McGraw-Hill, 1927.

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matter what our priority or property "rights" may be, to coordinate our electric systems so that they serve the greatest community good. Legislation and regulation do not develop neighborly duties; in a subject as complex as radio interference it is to be feared that they would add only confusion.

The complexity of the problem of location of the source of a complained of radio disturbance requires for its solution a radio and electrical engineer of extraordinary ability. The likelihood of any overhead wires, whether power, telegraph, telephone, or trolley, to propagate radio disturbances originating elsewhere, in much the same manner as any conductor will transmit carrier current or "wired wireless" signals, renders useless the triangulation or goniometer method of interference location in the vast majority of cases. The experienced investigator trusts the direction he obtains with the loop of his portable receiver only insofar as it tells him the paralleling overhead circuit from which he is receiving his greatest pick-up. This overhead circuit may in turn have received the interference from another paralleling circuit and so on. The "hot and cold" or maximum and minimum method of noise chasing, i.e., finding by trial and error the point of maximum disturbance, will best serve the investigator. Even with the use of this method the chances of error are great. With all the discontinuities and possible reflection points on an overhead electrical circuit, the interference may develop nodes and antinodes of effect on the receiver. In order to avoid self-deception the investigator using the "hot and cold" method must be on the alert for variation of coupling between his receiver and the overhead line under suspicion; many a man has been badly fooled by approaching, and thus making a closer coupling with, a vertical conductor on a pole. Care should also be taken that the investigator is not thrown off the scent by noises other than the one he is hunting. In fact his first duty should be to visit and keep in touch not only with the complainant but also with the complainant's neighbors and request their help in the search. Accurately kept logs of the interference are often invaluable in that they may help the investigator to tie up the interference with nearby factory operation, etc. The investigator needs neighborhood cooperation. Once he has determined the general source of the disturbance, common courtesy demands that the investigator immediately lay the problem before the person responsible in the home, factory, wire-using utility, or whatever the source might be.

The problem of elimination of known sources of interference is not an insuperable one. Standard filters, now on the market, will serve effectively in reducing that interference caused by the myriad

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of electrical appliances now in use. When it is considered that every arc or spark, no matter how infinitesimal, may give rise to a devastating noise in a radio receiver, it is obvious that a list of appliances to which it is necessary to add corrective devices would look like a complete catalog of electrical equipment. For the equipment of electric supply utilities good "radio maintenance" plus ordinary maintenance is desirable. Ordinarily the equipment of the power company is innocent of any radio harm; the much maligned "leaky transformer" is a myth. The electric railway and street car systems have a graver problem in that the sparking that occurs between trolley wheel

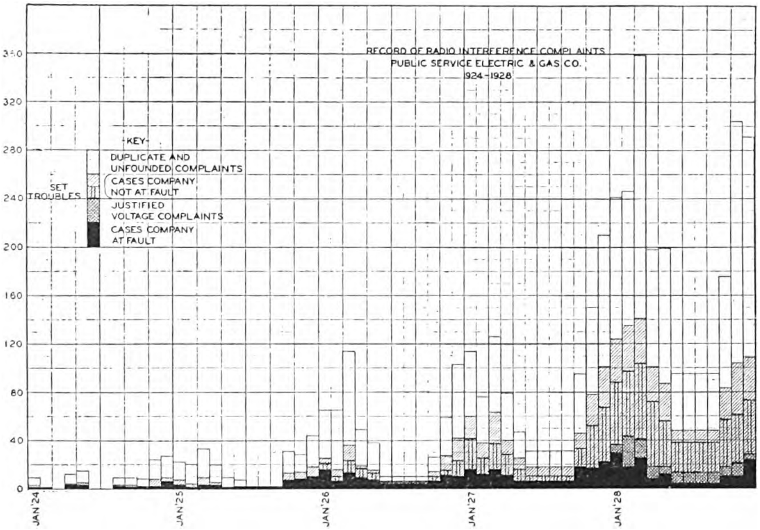

Fig. 1

and contact wire or between wheels and rails is a part of the normal operation of the system. The minor interference that occurs in the equipment of the communication systems is usually readily corrected by the proper placing of filters. For a more detailed account of the sources of interference and possible remedies reference to the August, 1927, Serial Report of the Inductive Coordination Committee, entitled Radio Coordination, Publication No. 267–98 of the National Electric Light Association, is recommended.

There remains the great body of minor noises which it is impossible to locate and some of which it would probably be impossible to remedy. These make up the "noise level" of the community below which operation of a receiver to bring in distant stations will give unsatis-

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factory results. This is the penalty of living in a civilized community where everything is done electrically. Someone has said that the only place absolutely satisfactory for radio reception would be a desert island reached by a rowboat and even there some complaint would be found against either thunderstorms or the aurora borealis. Even the automobile, of which there are now millions, adds its quota to the community noise level. Its ignition system will ruin reception if the receiver is placed close by, and at a wavelength of 10 meters passing cars drive the experimenter to distraction. It is obviously impractical to shield and ground the wiring and spark coils of every automobile in the country.

There seems to be no conspicuous offender in the generating of radio interference. An analysis of Fig. 1, a graph relating the experience of one of our large power companies with radio interference complaints, shows some disturbing trends in that it appears that the percentage of defective radio sets is increasing. Another interpretation, however, would be that the dealers and service men are becoming less keen in their diagnosis of troubles. Whatever the trend of interference troubles, however, the general problem remains the same. As in most problems that confront our civilization, tolerance is of prime necessity, and most important of all, community cooperation, in which is included a heavy responsibility on the engineering profession, must be achieved.

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UNITED STATES RADIO BROADCASTING DEVELOPMENT*

By

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Summary—*Part I of this paper gives in detail the development of radio broadcasting in the United States from 1907 to 1928, inclusive; Part II deals with the development of a radio broadcast from the studio to the listener. The characteristics and trends of these developments are then used for the purpose of pointing out possible future developments in radio broadcasting in Part III.*

Part I

At favorable locations we are now able to obtain considerable power in the form of satisfying musical frequencies from the last audio stage of our radio receivers. Though that has not always been the case, it is not to be attributed to any one thing or to a few things. Different viewpoints magnify different steps in broadcasting development to more than their proper proportions. Each class of contributors to broadcasting development sees that development through its profession, trade, vocation, avocation, science or product, and those who are still far from any broadcasting station may feel that broadcasting has developed very little.

Practically every radio device for sale to the public since 1921 has been advertised at one time or another as the one thing that will provide the listener with perfect reproduction. Makers of crystal detectors, vacuum tubes, loud speakers, resistance couplers, transformers, and receivers which take their power from electric light circuits, have been prominent in the making of that claim. As a matter of fact the equalizing of the wire lines to broadcasting stations[36] and the increasing of the power[7,15,37] of those stations were two of the important steps toward the quality we now get and we do not get perfect reproduction yet.[1,38]

To trace the steps in an effort to obtain a fair idea of their relative importance in developing the present reproduction, it is necessary to go back to the beginning[3] where we find that the term radio broadcasting is absurd in a sense because radio and broadcasting are, in a sense, synonyms. The term radio supplanted the term wireless because this means of communication which we named "radio" uses conspicuous wires and because the characteristic wave in this form of com-

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munication explodes from about the antenna; that is, the wave is broadcast along every radius from the antenna. The term radio, taken from radii, was originally meant to indicate that the waves were broadcast. That is the essence of the reasoning of the Standards Committee of the Institute of Radio Engineers[2] as I recall it when they standardized the term radio in 1913. That committee at the same time coined and standardized also the term "audio" for the frequencies we can hear. Their action and the cooperation of the government fixed those words in our language.

True radio is broadcasting, and has been used for that purpose for thirty years,[3] particularly to broadcast distress signals, ships' position signals, and time signals in telegraph code. Also, radio has been used to broadcast speech for more than twenty years. The broadcast of the orchestra type of music has been under development for about twenty years. To broadcast speech required further development from the radio telegraph stage, and to broadcast satisfactory music required still further development.[5,7] In the scope of modern broadcasting, radio has become natural, for broadcasting is what radio is. However, to broadcast over a wide area a large part of the musical scale with fidelity and to deliver a considerable amount of power has required many steps over a period of years in the development of broadcasting devices and in the removal of interferences.

It was an early belief that radio would find more use if it could be made to carry speech. It was believed, for example, that steamships that were reluctant to bear the expense of radio telegraph operators would install radio telephones if the expense of carrying operators who understood code signals could be avoided in that way. Therefore, early attempts were made to provide a radio telephone.[1]

The first radio transmitters in service could not transmit speech because they made short, noisy groups of waves from spark discharges.[3] To carry speech the waves could not be in such noisy groups. Continuous waves or their equivalent became obviously necessary to produce radio telephony.

Several continuous wave generators were developed.[1,30,66] Of these the arc radio generator was the most practical because of its simplicity. It was about as simple as an arc light.[22] It was an electric arc flowing in a gap between a cool copper electrode and a carbon electrode and in an alcohol flame—sometimes in a magnetic field. A small coil of wire and an electrical condenser were connected in parallel to the arc. The coil and condenser determined the number of radio waves that would be produced. The simplicity of that device made it possible for many people to try to develop radio telephony with it in many

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places. Therefore, several professional and amateur radio people made such radio phones in several places.[23]

Four of the years are of peculiar interest; 1907 because it was in a

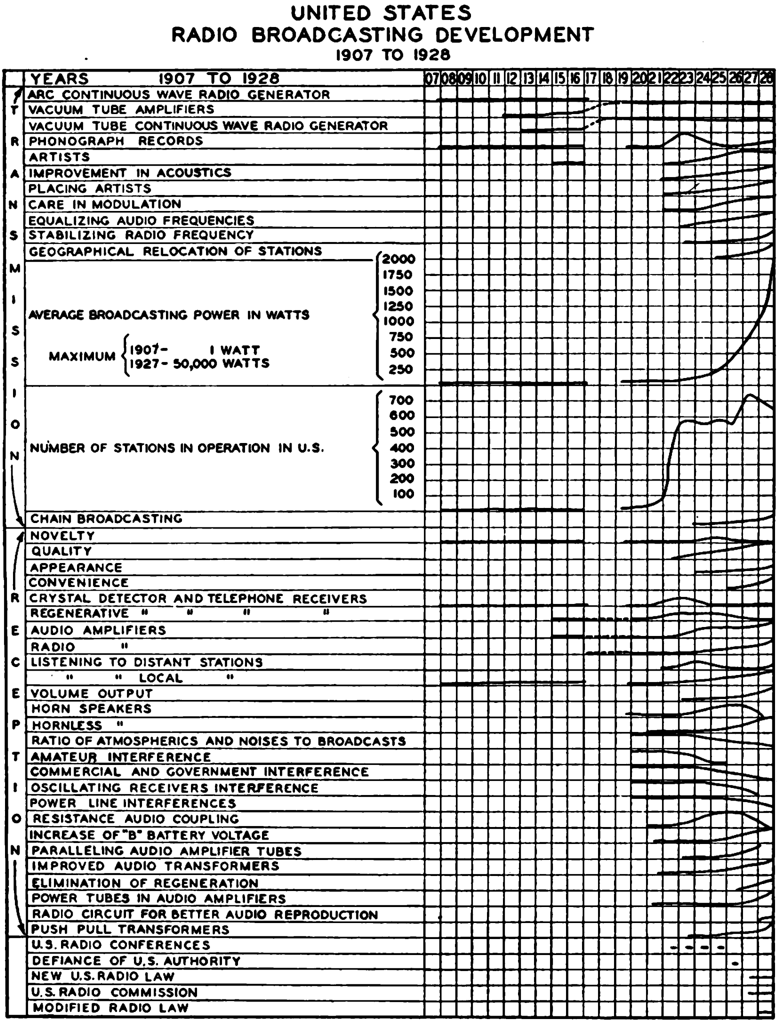

Fig. 1

way the beginning; 1917 and 1918 because in this period broadcasting was prohibited but the abnormal quantity of radio apparatus and activity for the war during that time contributed to the very rapid growth of broadcasting; and 1921 because from then on broadcasting

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has been growing rapidly and at about that time broadcasting emerged from the socalled trial stage into the worth-while service stage.

By referring to the chart marked "United States Radio Broadcasting Development" we can follow with fewer words the steps from the first broadcasting of a little music, to the present far flung broadcasting of more satisfactory music.

Chart of United States Radio Broadcasting Development

In this chart, the left half is devoted to the steps or factors which have been used in the development of broadcasting. At the right the chart is divided into vertical sections representing years. Little curves are shown in the spaces under the years and opposite the steps or factors to indicate when those steps or factors first appeared and when they became prominent in the development. The curves relating to broadcasting power and to the number of stations are drawn to scale. The other curves are not to scale.

Arc Continuous Wave Radio Generator

As we see by the chart, broadcasting by use of the arc began in the winter of 1907 and 1908. At that time President Roosevelt sent the United States naval fleet around the world. These vessels had been equipped with arc telephones.[25,26,27] The navy operators placed phonographs before the microphones of those arc telephones playing phonograph music into the microphones and thereby broadcasting music. That music was picked up by the other ships of the navy, by commercial ships, and by numerous shore stations as the fleet proceeded on its way around the world. That took several months. Now broadcasting can go around the world in a fraction of a second.

During 1908 Dr. DeForest broadcast music from a station in New York City, using an arc radio telephone transmitter, and during the same year, using a similar apparatus, I broadcast music from a station at Manhattan Beach, New York. We both used phonographs except when we talked into the microphone ourselves. There was, however, one important exception to that during 1909, when Dr. DeForest installed a microphone in the Metropolitan Opera House on the stage and broadcast Caruso's voice. That was probably the first case of directly broadcasting the work of a distinguished artist. At that time we were fundamentally trying to develop a radio telephone;[29] however, we considered the possibility of broadcasting as it is done now, but at that same time, 1908, there was on Broadway near the corner of 40th Street a device called the "Cahill Telharmonium," which was built for the purpose of broadcasting music over wire lines such as telephone lines. That Telharmonium device failed to meet popular favor and

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caused us to have some doubt about the possibility of the public desiring to hear music broadcast. We believe now that device failed to be popular because of the quality of the music and for economic reasons.

A printed record of the optimistic thoughts at that time on the possibilities of radio broadcasting is on page one, in column three, of the New York Times of February 14, 1909, entitled, "De Forest Tells of a New Wireless." The article states that it quotes from a speech which Dr. De Forest had given the night before at Fraunce's Tavern. The article reads in part as follows:

> "I look forward to the day when by this means (wireless phone) the opera may be brought into every home. Some day the news and even advertising will be sent out to the public over the wireless telephone."

Broadcasting with the arc type of continuous radio wave generators continued in various parts of the United States until unnecessary stations were closed by order of the Government when we went into the world war in 1917.

Early in the use of the arc it was apparent that the distance which could be reached was almost entirely limited by the amount of power that an ordinary telephone microphone could handle.[1,29] Also, the arc generator was lacking to a considerable extent in stability, making it not wholly desirable for telephone transmission. In addition, the arc was not well adapted for generating a considerable amount of power on the shorter wavelengths as used then, which waves are better adapted for the transmission of speech. The microphone, of course, was limited in the amount of movement that could be obtained for varying the power by the amount of energy which could be picked up from the sound waves in the air due to the voice or music. Therefore, it became obvious early that either a microphone which would regulate a very large amount of power compared to the amount of power in the air waves which were driving the microphone was necessary,[1] or else some device was necessary to amplify the sound frequencies or audio frequencies that could be obtained from the movement of an ordinary microphone driven by the ordinary air waves. This latter device proved to be the device which would make it possible to handle a greater amount of power; that is, an amplifier was provided[39] which would amplify the audio frequencies obtained from the microphone.

Vacuum-Tube Amplifiers*

In 1911, it became fairly apparent that the vacuum tube, then called the "audion," could be used to amplify telephone currents and

* See reference 39.

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this use of the vacuum tube as an amplifier gradually increased until in 1914, 1915, and 1916 they were not only placed on the market somewhat but were used considerably by the United States Government.

When this country entered the war in 1917, the government ordered various types of these vacuum-tube amplifiers in very large quantities and thereby produced an overstock of such amplifiers including the vacuum tubes which were a necessary part. Also, the war caused the govenment to train a very large number of people relative to radio subjects so that after the war was over there was an excess of amplifier material and an excess of people who were interested in radio. Amplifiers were manufactured to a very large extent during the war, and, of course, have been very highly developed since that time. These amplifiers were one of the very important factors in building up broadcasting.

The vacuum-tube amplifier as such and as a radio generator[40] was the largest contributing factor to the satisfactory use of the loud speaker, which is the conspicuous part of the broadcasting of the present day.

Vacuum-Tube Continuous Wave Radio Generator

In 1913, or earlier, it was discovered that the vacuum-tube amplifier was not only capable of amplifying audio frequencies such as are used in telephone work, but was also capable of amplifying radio frequencies, and it was found that by taking some of the amplified radio frequency and feeding it back into the vacuum tube it was possible to make the vacuum tube become a continuous wave radio generator. The portion of the radio frequency which was not fed back could be used for radio signaling purposes and therefore was useful for that purpose. Also, it was found that such radio-frequency generators were capable of working well at wavelengths such as are suitable for radio telephony. Since Edwin H. Armstrong partially disclosed his results in discussion following a paper delivered before the Institute on December 2, 1914, there has been continuous activity in the development of vacuum-tube radio generators.[40] This use of the vacuum tube as a radio-frequency generator became quite noticeable by 1915 and 1916, and resulted in the manufacture of radio telephones which consisted of a combination of the vacuum-tube audio-frequency amplifier and the vacuum-tube radio generator.

In 1915, during the month of September, radio telephony was accomplished from the naval radio station at Arlington, Virginia, to Mare Island Navy Yard, California, using these vacuum-tube gen-

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erators and vacuum-tube amplifiers.[16] That demonstration contributed indirectly to broadcasting development. That radio telephone experiment was also heard in the Hawaiian Islands and in France.

With the beginning of the war the government desired radio telephones, and therefore both the army and navy ordered the building of a large number of radio telephones comprising vacuum-tube amplifiers and vacuum-tube generators.[4] The number was far beyond the needs of the government at the close of the war; also, the close of the war found a large number of these radio telephones on ships and at other points. Even the sub-chasers were equipped with radio telephones and a great many of these radio telephones were actually used for broadcasting phonograph music just as the little arc phones had been used before the war. The type of radiophone, known as CW936 now on exhibition at the Smithsonian Institute, was a common example.

Our amateurs with their adventurous and pioneering characteristics that have done so much for radio took a great interest in these radio telephones.[57] Many of these amateurs were ex-service radio men.

"The Broadcasters Were Phonograph Records"

The first broadcasting was nearly all by the simple broadcasting of the voice or by placing a phonograph in front of the microphone of the radio telephone whether that radio telephone was of the arc type or the later vacuum-tube type. In the years immediately following the war, particularly 1919 and 1920, a number of people apparently used the tube type of radio telephone to broadcast voice and phonograph music.[11] One of these persons was Frank Conrad who lived near Pittsburgh, Pennsylvania.[7,11] He broadcast phonograph music and the people of Pittsburgh became so impressed that the Westinghouse Electric and Manufacturing Company, at Pittsburgh, also became interested. In November, 1920, they obtained a United States government license to broadcast information and music. Because they obtained the first specific license for such a purpose, it is sometimes said to be the beginning of broadcasting; rather, it was the beginning of the ending of the opinion that broadcasting is child's play. Immediately after that time many other broadcasting stations using tube generators went into service. Our amateurs were the first audience.[49] Probably in all of the United States, 5000 amateurs were equipped to listen at that time. A great deal of the first advertising of radio receivers was directed at them; for example, the Westinghouse advertisements.[44,46] For a time the Westinghouse Company was the most prominent in broadcasting.[45] In the vernacular, the prestige of

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the Westinghouse Company sold the broadcasting idea to the public. The idea had existed for a long time. If the American Telephone and Telegraph Company had used their 1915 station for broadcasting they probably would have sold the idea five years earlier.

Artists Broadcast

By the latter part of 1921 and particularly in 1922, artists were brought in to sing or play on instruments taking the place of the phonograph records. Artists, of course, had previously been used, for example when De Forest had broadcast Caruso's voice in 1909, and I have heard artists broadcasting and have seen them broadcast from the arc broadcasting station in San Francisco as far back as 1915 and 1916. Beginning about 1922 and continuing in increasing numbers to the present time, artists have been used for broadcasting purposes. The use of phonograph records for broadcasting purposes began to fall off in 1923 and the phonograph is less extensively used for broadcasting purposes at the present time, the effort being to provide the broadcast listeners with higher quality of music than could be obtained when the phonograph was used. Chain broadcasting instead of records has been employed more and more since 1923 to distribute the productions of distinguished speakers and artists over a wide area. However, specially cut records reproducing low notes and adapted for special release in approximately simultaneous reproduction at various stations are advocated at the present time.

Improvement in Acoustics*

The next step on the part of broadcasters to provide the broadcast listeners with improved quality was in the improvement of the acoustics in the rooms or studios where the artists sang or played. It was soon found that the walls must be properly softened and draped to provide as good quality as can be provided from such artists and those improvements have been continuing up to the present time.

The softening of the walls was overdone at first by beginners, resulting in stronger low notes and too little reverberation for high notes. The stronger low notes were not apparent to the listener, however, because the common amplifier transformers did not pass them on to the loud speaker. The presence of people in the studio decreases reverberation; therefore, drapes are now shifted to offset the excess or lack of people in the studio.

* See reference 7, 18, 32, 41.

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Placing Artists†

It was also discovered that it is necessary to place the artists relative to the microphone, or the microphones, where a number were used, relative to the instruments in such a way that a proper balance of the music would be picked up, and to prevent blasting or overloading of the microphone.

Care in Modulation

It was also found that considerable care was necessary in modulation of the radio carrier wave to prevent distortions and undesirable sounds being sent to the broadcast listeners and to decrease the shifting of carrier frequency. Since the putting into use of the master oscillator and power amplifier it has been possible to increase the modulation without changing the radio frequency, with the result that the relative service range has been increased with respect to the total power used and to the nuisance range of the carrier.

Equalizing Audio Frequencies

After all of these efforts had been made to provide the broadcast listener with some satisfactory music, it was found that the audio-frequency circuits used in broadcasting discriminated against the higher audio frequencies, permitting the lower audio frequencies to go through with more power than the higher audio frequencies. Therefore, beginning about 1923 and continuing to the present time, various improvements in the equalizing of the audio frequencies have been put into effect so that the listener may get a better degree of fidelity from his radio receiver. Also, so that distortions or added interfering noises may not result, orchestra productions which may vary in power from a million to one are changed by controls to ratios of about ten thousand to one in the broadcasting circuits.

Stabilizing Radio Frequencies

As early as 1923 it was found that it is necessary to stabilize the radio frequency of the station in order to provide better fidelity in the transmission of the mechanical or audio frequencies. Improvements in stabilizing the radio frequencies have been going on ever since and are being carried on persistently at the present time. Now the stations are controlled by standardized crystal oscillators, and the modulation is sometimes after the generation to provide more accurate radio frequency.[19,35,37]

† See reference 10.

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The better transmitters are controlled by temperature-controlled crystals. Laboratory results indicate that crystal controls that can be held accurate to one cycle or better for the frequencies used in the broadcast band are practicable. It is expected that heterodyne squeals between stations in the same channel will be eliminated and practical synchronization may result from further accuracy in frequency maintenance.

Geographical Relocation of Stations*

By 1925 it was found that a geographical relocation of some of the stations was necessary in order to provide densely populated districts with a good strength of broadcast signal without providing interference in the reception from other broadcast stations. Therefore, beginning in 1925, some of the stations which were formerly located in the cities, as for example in New York, were moved to less densely populated districts, and this practice is being continued.

Average Broadcasting Power†

As will be seen in the chart, there is a curve indicating the average broadcasting power in watts used in the United States between 1907 and 1928. These powers were taken from the best available records, however, there has not been a uniform standard in power rating; therefore, this curve must be considered with that in mind.

In 1907 and up to about 1917 when the power was limited by the amount of power that could be handled by microphones, the actual transmitted power used for broadcasting was probably seldom in excess of one watt. At the present time the maximum power used for every day broadcasting is as high as 50,000 watts.

The curve of average broadcasting power indicates that the present average is over 1900 watts. According to government records there were still some small broadcasting stations in 1928 of no more power than were first used in 1919 and 1920, namely, of about five watts. Fair service broadcasting is roughly estimated by some at 5 watts for one mile, 500 watts for ten miles, and 50,000 watts for one hundred miles,[15] but five watts may be heard 1000 miles on a winter night and any amount of power will usually fade at one hundred miles, all of which causes confusion and misunderstanding on the part of the uninitiated.

Increasing the power not only gave stations greater ranges but it overcame or rode over noises due to atmospherics and other electrical disturbances. Where power has been increased it has contributed

* See reference 15.
† See reference 21.

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materially to the quality that can be obtained from radio receivers. Also increasing power has frequently resulted in interferences such as heterodyne notes, cross talk in channels, and cross talk between channels.

While we are dealing with the United States only, it is well to mention that the rest of the world recognizes broadcasting and the value of power. For example, according to the Department of Commerce report for February, 1928, over 200 stations in the Eastern Hemisphere used more than 200 watts for broadcasting and nearly 30 stations in South America used over 500 watts.

Number of Stations in Operation*

The curve showing the number of stations in operation shows that there were very few stations in operation from 1907 to 1917 when they were closed in 1917 by the war and a few again in operation in 1919, increasing in 1920 and jumping upward in 1921 and 1922 to over 500 stations and continuing at over 500 stations until in 1926 when the total number of stations, during that period, was kept fairly level by the United States government acting through the Department of Commerce. However, in 1926, the authority of the government practically broke down and there was a sudden increase in stations so that in 1927 there were over 700 broadcasting stations in the United States. The new law went into effect also in 1927 and stopped the rise at about 710. Since then the number has decreased to nearer 600 and under the November 11, 1928 allocation the number of stations on the air at the same time is decreased. As yet there is no apparent limit to the number who would broadcast if they could get permission.

On December 1, 1921, the Department of Commerce assigned broadcasting of music and entertainment to one wavelength, 360 meters, and the broadcasting of agriculture and weather reports to another wavelength, 485 meters.

From then on broadcasting expanded to take up nearly all of the little used band of waves between the amateurs at 200 meters and the distress wavelength at 600 meters.

On April 8, 1922, the Department of Commerce assigned class "B" stations to broadcasting on 400 meters. Class "B" stations were of 500 watts or over, and were not permitted to broadcast phonograph or other mechanical music.

On April 2, 1923, the 10-kc separation between broadcasting stations was put into effect, class "B" stations were placed on the waves from 300 to 345 and from 375 to 545 meters. Stations were left on

* See reference 21.

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360 meters under the title of class "C." Class "A" stations of low power that broadcast phonograph music were placed on about 230 to 300 meters.

In about February, 1925, the band was widened by assigning stations as low in wavelength as about 205 meters, and in April, 1925, to as low as about 200 meters.

Since then the broadcasting band has settled down to from about 200 to 545 meters, or from 1500 to 550 kc. Of these frequencies, 730, 840, 910, 960, and 1030 kc are used by Canada only, while 580, 600, 630, 780, 880, 890, 930, 1010, 1120, 1200, and 1210 are shared with Canada; 690 is shared between Canada and the U. S. Naval station NAA, making a total of 90 carrier frequencies now in use in the United States for broadcasting music, entertainment, etc. The assignment of stations to clear and common channels has changed until since the zone requirement of the Act of 1928 (amending the Act of 1927) went into effect, only one station at a time has been allowed to operate on each of forty frequencies at night, while from two to twenty-five stations have been permitted to operate at one time on the other fifty frequencies.

The increase in power was brought about by the demand for not only the kind of broadcasting service that would enable a listener to hear a broadcasting station, but would enable the listener to get good quality reproduction from a broadcasting station.[37] The number of stations provided all over the United States and in the United States possessions enabled practically all of the people in the United States and in its possessions to hear a broadcasting station, the quality depending somewhat upon the amount of power of the station and the distance from the station. Increasing power has always apparently contributed to improvement of quality up to at least seventy miles from a station. Beyond seventy miles the quality or the entire signal may be lost at times due to fading. Fading may occur over much shorter distances at times. If receivers were suitable and enough wavelengths were available, a good distribution of high quality could be obtained by placing high power stations over the entire country about 100 miles apart; but that is an ideal that seems to be far from the practical possibilities.

Chain Broadcasting

In providing quality by the use of famous artists it was found that the greatest number of such artists are available near the theatrical centers of the larger cities, and that it is more expensive or sometimes impossible to take them to out-of-the-way broadcasting stations.

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The theatrical centers of large cities did not prove to be the normal place to locate the broadcast transmitters. Therefore the studios were constructed and located to suit the artists and connected to the broadcasting stations by wire lines.

Owing to fading and noise levels of man-made interference, and atmospheric interferences, it has proved impossible up to the present time to build a sufficiently powerful broadcasting station to give consistently good quality over any large portion of the United States. Therefore, exceptionally good artists are collected at one studio and a number of broadcasting stations in different parts of the United States are connected by wire lines to that one studio. That method of furnishing the program from one studio to a number of stations is called "chain broadcasting." The successive stations and intermediate wire lines make up the chain.

This "chain broadcasting" started seriously in 1923 and has increased until there are several such chains in operation now, with sometimes thirty or more stations on one chain. In 1927 as many as 69 stations, using 28,500 miles of wire, were said to have been used in one chain broadcast.[36] One chain broadcasting system is said to have had at the end of 1928 sixty-three broadcast outlets and 14,800 circuit miles of wire.

"Chain broadcasting" in which the stations transmit on the same frequency has been in operation for about five years, with two stations WBZ and WBZA at Springfield and Boston, Massachusetts.

All of the foregoing steps were toward not only the distribution of broadcasting but very largely, if not chiefly, toward the production of better quality for the greatest number of broadcast listeners.

Reception

In the matter of broadcasting development there are, of course, two ends to the broadcasting. One is the transmission end which we have been considering and the other is the reception end which we will now consider.

The type of receiving apparatus is very important to the quality and strength of the sounds delivered by the loud speaker. The latter gives out to the best of its ability what is received, and poor reception should not be blamed on the speaker. Poor reception due to faults ahead of the speaker cannot be improved by the speaker to any great extent.

Novelty

From 1907 to 1917, and from 1919 to 1922, listening to broadcasting was largely a matter of novelty, the novelty of receiving music from

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out of the air and the novelty of receiving music or speech from very great distances. Many of the early listeners were not particularly interested in the music or in anything the broadcaster said except what he said about the location of his station. Listeners desired to receive from as great a distance as possible, and from as great a number of stations as possible. However, all of that novelty did not wear to the present time. It reached its peak in the winter of 1924 and 1925, and the matter of receiving great distances or numerous stations no longer appeals to relatively as great a number of people. The clearing of forty channels on November 11, 1928 made more long distance reception possible with the result that such reception increased somewhat during recent winter months. Many novelty hunters and pioneers are now looking forward to television to provide a thrill.

Quality

As early as 1922 there was some apparent desire for quality broadcast reception rather than an interest in the novelty of the thing. That desire for quality has continued steadily until the desire for quality is now the common desire on the part of the broadcast listeners in the United States.

Appearance and Convenience

There was, of course, a desire particularly on the part of women for good appearance of the radio receiving apparatus and a desire for radio receiving apparatus that was convenient. And the convenience has reached quite a high point particularly during the years 1926, 1927, and 1928. The single control receiver and the receiver that operates from the lighting circuit are far more convenient than former receivers.

Crystal Detector and Telephone Receivers

In the early broadcast reception, back in 1907, and continuing to 1922, the simple crystal detector and telephone receivers were used. With the advent of considerable broadcasting, they increased in numbers reaching a maximum in about 1922 and 1923, and then decreased until at the present time comparatively few of them are used. With such an arrangement the reception was limited to one or two people listening with head telephone receivers.

Regenerative Detector and Telephone Receivers

Also, in the arc broadcasting, as early as 1914, and until the time of the war and in the tube broadcasting after the war, the regenerative

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tube and telephone receivers were used. Their use reached a peak in about 1923 and since then has gradually fallen off. The regenerative detector and telephone receivers were probably the most efficient method of receiving broadcast from the standpoint of the ratio of attainable distance to the amount of power and apparatus used. However, the regenerative receiver spoiled the quality of the sound. As used, it frequently favored low notes and frequently produced interference in other receivers.

AUDIO AMPLIFIERS*

Audio amplifiers were used before the war and after the war, but did not come into great active use until slightly after the activity in the rejuvenated broadcasting in 1921. But those early amplifiers were best suited to amplifying only one or a few audio frequencies, such as the 1000-cycle note used in telegraphy. Their use has been on the increase since that time, both in numbers used and in the quality of the amplifiers used. Audio amplifiers are primarily for giving power in the output circuit of the receiver. It is this power that makes the use of a loud speaker possible.

RADIO AMPLIFIERS†

During the war there were developed some radio amplifiers and various forms of these were used for the reception of broadcast when broadcasting became active after 1920, but they did not come into general use until the latter part of 1923. Their use increased steadily until now practically all radio receivers contain radio amplifiers.

RECEPTION OF DISTANT STATIONS VS. RECEPTION OF LOCAL STATIONS

As was said before, the first era in popular broadcast reception was that of novelty and of listening to distant stations. This reached a peak in the winter of 1924–1925, and has decreased. In 1922 many believed that broadcast listeners would lose all interest in a short time because they recognized nothing but novelty in broadcasting.[48] Lack of quality and lack of financial support were also frequently prophesied for future broadcasting. Reception of local stations was, of course, per force, what was done in the early broadcasting before the war, and beginning about 1922 the reception of local stations has steadily increased, inasmuch as reception of local stations was preferable to listening to distant stations, the quality being so much better. Therefore, we have a steady increase in local station reception where people are so situated that they can listen to local stations. Any station over

* See reference 39.
† See references 43, 47, and 65.

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70 miles away fades. Also, a radio circuit which will pick up stations over a long radius will pick up the atmospheric disturbances within that radius. Chain broadcasting is a result of the desire to listen to local stations.[36] A large part of the rural population listen to distant stations either because there are no local stations or because there are no satisfactory local stations. Many metropolitan listeners can receive only local stations because their receivers will not cut out the locals and bring in the distant stations.

Volume Output

The volume output of the receiver was very small from 1907 to 1922; after 1922 the increase in power of the transmitting stations occurred and the use of radio and audio amplifiers became effective. By the combination of the increase of transmitted power and the use of radio[43] and audio amplifiers in the receivers it has been possible to obtain a much higher volume output.

Horn Speakers*

With the possibility of obtaining a higher volume output so that it was no longer necessary to listen to a broadcast by clamping the head telephones to the ears, the horn type loud speakers came into the market in greater numbers.[46] Such speakers have existed for a number of years,[28] for example, in railway stations for announcing the arrival and departure of trains and for such special uses. Those same types of horn speakers were then put into use as broadcast loud speakers, and continued to be widely used up to about 1925, since when there has been a decrease in the amount of their use. The horn speakers gave cavity sounds due to the horn. Also, the diaphragms used in the horn speakers were usually of metal or mica and therefore gave metallic or sharp sounds. The early horns themselves were metallic, which contributed to the metallic sounds. The bi-polar telephone receivers used with horns rectified the sounds to some extent, making false higher sounds and spoiling lower sounds.[54] The horn speakers concentrated the sound in one direction, which was not entirely satisfactory for reception of broadcast at any part of the home. The horn speakers were more or less unsightly and were objected to from the standpoint of their appearance. Most of the cabinet or console type of radio receivers made before 1928 contain horn speakers but their unsightliness is covered up. Some of the horn speakers which were carefully designed and were of considerable length gave very satisfactory results; however, their size (6 to 8 feet in length, with a bell opening of 30 to

* See references 53 and 54.

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40 inches in diameter) rendered them impractical for the general radio user.[53] At the present time, some people prefer the older type of horn speakers because they do not muffle the high notes and harmonics as much as the later forms of speakers with softer diaphragms. They are used for high quality extensive public music and voice as in talking pictures of the Vitaphone and Movietone systems,[33] and public address systems.

Hornless Speakers*

Hornless speakers were put into use as early as 1921, and began to be popular in about 1925. Their popularity has continued up to the present.

The early hornless speakers were not as sensitive as the horn speakers, and therefore did not give sufficient volume until the output of the broadcast stations and the amplifying power of the radio receiving sets had been increased. They, therefore, came in at a time when the improvement in the quality of the output of radio receivers had been considerably increased. The bi-polar type of driver with its distorting effects was not so applicable to them; therefore, its defects were not inherited by the hornless speakers as a rule. The moving coil or "dynamic" driver was one of the first used in loud speakers for radio reception, but it did not become popular until the recent advent of more available power. The condenser type of speaker has been repeatedly offered and now shows some likelihood of coming into use.

Ratio of Atmospherics and Noises to Broadcast

Noises are not eliminated by the structure of the loud speaker when the speaker is capable of reproducing a reasonably satisfactory portion of the musical scale. A high quality broadcast without noises when fed to many forms of speakers gives some pleasing results.

Broadcasts are not only spoiled by improper transmission of sound or audio frequencies, but they are spoiled by interferences such as static or atmospherics which are due to natural electric discharges in the atmosphere, and also by interferences caused by sparking on electric circuits for motors, lights, etc. By increasing the power of the broadcasting stations the ratio of the strength of the interferences due to atmospherics and other similar noises has been greatly reduced in localities not too far removed from the high powered broadcasting stations. The noises have been so overridden by the increased power of broadcasting stations with high modulation that even in the summertime in some parts of the city of New York there are only a

* See references 59, 60, and 61.

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few times in which atmospherics interfere with the quality of received broadcast to such an extent that the listener shuts off his receiver.

Amateur, Commercial, and Government Interference*

Another form of interference which was annoying in the early popular status of broadcast reception was that due to amateurs who were sending on spark transmitters. However, the amateurs largely of their own accord[48,52] beginning in 1922, through their organized methods rapidly discontinued the use of such transmitters until now we have practically no interference from that source. The commercial and government spark and arc stations also produced interference. There is still some interference from commercial spark stations on ships. The sibilant and transient characteristics of spark and arc interference made them more apparent as a rule from the hard diaphragm used in horn speakers, than from the softer muffling type of paper hornless speakers.

Oscillating Receiver Interference

Another form of interference was prevalent in the forepart of the popular broadcasting era beginning in 1921; that was due to oscillatory receivers. The regenerative type of receiver was often so adjusted that it oscillated, thereby becoming approximately a 1-watt transmitter which produced a squeal in other receivers. That has been gradually discontinued since the latter part of 1925.

Electric Light and Power Line Interference†

The interference from power and lighting lines, x-ray machines, etc., has been decreased somewhat since 1925, due to protests on the part of the public.

Resistance Coupling in Audio Amplifiers‡

Since the beginning of popular broadcasting and the use of audio-frequency amplifiers, there have been used what is known as resistance coupled amplifiers. These amplifiers when properly constructed do not discriminate to a detrimental extent against any of the sound or audio frequencies, and therefore in themselves do not spoil music. However, they do not amplify as much as the transformer coupled amplifiers. Therefore, transformer coupled amplifiers were used mainly in the beginning when there was not so much power to amplify, but it soon

* See reference 71.
† See reference 71.
‡ See references 43, 67, 68, 69, and 70.

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became apparent that they were spoiling the quality of the music as received by the broadcast listener. Early transformers were copied after transformers which had developed to pass the spark and arc telegraph note, or pitch, of about 1000 cycles. They had not been designed to handle the musical scale. The manufacturers of resistance coupled amplifiers informed the broadcast listeners that the transformer coupled amplifiers did not reproduce the bass notes of the music, nor did they reproduce the high notes as satisfactorily as they should. At the same time the listeners were informed that resistance coupled amplifiers reproduced all notes equally well. Therefore, beginning in 1923 and reaching a peak in 1925, the resistance coupled amplifiers were put into considerable use by people who wanted better quality in their broadcast reception.

Increase of Plate Voltages

It was found that the vacuum tubes could not be used to produce the desired loud sounds with the voltages that were being used on the "B" battery circuit, without distortion. Lack of low notes, rasping sounds, and changes in pitch resulted from this distortion. By increasing the "B" battery voltages more power was delivered to the loud speaker with less distortion, and therefore since 1925 there has been an increase in the plate voltage.

Parallel Tubes in the Last Stage of the Audio Amplifier

Even with the increased plate voltage it was found there was still some distortion; therefore, in 1926 and 1927 two tubes were used frequently in parallel in the last stage of the amplifier as a further attempt to get enough distortionless power for the loud speaker.

Improved Audio Transformers

By the beginning of 1926 all of the manufacturers of audio-frequency transformers had seen from the growing popularity of resistance coupling and large transformers that it was necessary for them to improve their transformers so that better reproduction could be obtained through the audio-frequency amplifier. Accordingly they put on the market improved audio-frequency transformers using a greater amount of iron, a better quality of iron, and more suitable windings to transform audio-frequency currents without the former undesirable distortion which had been obtained when using such transformers. The general improvement has been very noticeable.

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Elimination of Regeneration

In 1926 and 1927 it also became apparent that the use of regeneration in receivers intentionally or unintentionally was detrimental to the output of sound obtained from the receiver; therefore, more active steps were taken to do away with all regeneration, careful shielding[56] of coils from each other, neutralization, phase shifting, and various other arrangements and methods were employed to prevent the low, hollow sounds and heterodyne squeals due to regeneration.

Power Tubes in Audio Amplifiers

Since it had been found that paralleling tubes were desirable to get better quality, new tubes were designed called audio-frequency output tubes or power tubes to be used in the last stage of the radio apparatus. These handle a sufficient amount of current to operate the loud speaker at more volume and with less distortion due to the tube. These higher power tubes came into active use beginning the latter part of 1926, and are continuing to the present time as a noteworthy factor for increasing quality.

Radio Circuits for Better Audio Reproduction*

At the first of the year 1928, some public attention was given to improved radio-frequency circuits which will receive all of the radio frequencies involved in a broadcast transmission sufficiently well to better preserve the quality of the music. This is called broad band reception. It is intended to receive all the radio frequencies produced by one station equally well so that the higher notes and harmonics will arrive at the speaker in proper force. Also band reception of this type is intended to exclude all other frequencies such as crosstalk from adjacent channels, thereby reducing interference. There is need for great improvement along those lines and along the lines of making receivers that will cover the entire broadcasting band uniformly.

Push-Pull Transformers in Audio Amplifiers

For a number of years there has been used an arrangement of transformers for the last stage of audio-frequency amplification called the push-pull, which when properly constructed and used with the proper tubes has been very beneficial in producing high quality music. This arrangement has come into service considerably in 1928 to improve the quality of broadcast reception.

* See reference 38.

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United States Radio Conferences

Related to the apparatus both in transmission or reception, other means have been used to improve the quality of broadcast reception. For example, in 1922, 1923, 1924, and 1925, Secretary Hoover of the Department of Commerce called a conference of people engaged in all phases of broadcasting and people listening to broadcast for the purposes of trying to control the broadcasting so that more satisfactory results could be obtained by the broadcast listener.

Defiance of United States Authority

That conference action benefited the transmission and reception of broadcasts but was discontinued in 1926 because a broadcaster in Chicago defied the United States authority and used a wavelength not authorized. When the Department of Commerce brought suit the courts upheld the action of the broadcast station, thereby curtailing the power of the Department of Commerce.

New United States Radio Law and Federal Radio Commission*

The matter of delivery of satisfactory high quality broadcast to the listener was of such importance that the 69th Congress in 1927 passed a new radio law intended to correct the weakness of the government and enable the government to aid the public in obtaining satisfactory radio service, and furthermore, for that purpose a special Federal Radio Commission was appointed. The chief inspiring objective of that law and of a large part of radio and acoustical engineering of the past twenty years has been to deliver to all broadcast listeners all notes of the musical scale at their proper strengths, without interference.

The following is an extract from a report of the Federal Radio Commission:

> The passage of the radio act of 1927 presented a situation without parallel in the history of American executive departments. A wholly new Federal body was called into being to deal with a condition which had become almost hopelessly involved during the months following July 3, 1926, when it had become clear that the Department of Commerce had no authority under the 1912 radio law to allocate frequencies, withhold radio licenses, or regulate power or hours of transmission. The new law itself was, of course, totally untested, and the Federal Radio Commission was called upon to administer it with no clear knowledge as to the limitations which might be created by subsequent court action.
>
> The act embraces the whole field of radio communication, but public interest was concentrated almost wholly on the single section of it

† See reference 73.

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devoted to radio broadcasting. The problems of point-to-point radio communication, of radio-telegraphy, of marine wireless, of power transmission, etc., though of vast importance, did not present such an urgent need for immediate action as the utter confusion within the broadcasting band. Public opinion assumed that the prime purpose of the law in creating the Federal Radio Commission was the immediate establishment of a sound basis, in the interest of the radio broadcast listener, for the orderly development of American broadcasting.

For this reason the work of the Federal Radio Commission from its first meeting on March 15, 1927, up to June 30, was devoted almost exclusively to clearing up the broadcasting situation. With the physical capacity of the available channels, or wavelengths, already far exceeded by the number of stations actually in operation, and with no provision in the law for the Federal acquisition or condemnation of broadcasting stations in order to reduce the total number, the commission found it necessary to evolve some plan whereby, without any unconstitutional exercise of arbitrary authority, the listening public could receive more dependable broadcasting service, and whereby a gradual and orderly development could be counted on to bring about a progressive reduction in radio interference.

The following record, taken largely from the orders and bulletins of the commission, outlines the steps whereby this plan was evolved and put into execution. These steps were, in brief, four: First, the determination of the best scientific opinion through a series of public hearings; second, the internal organization of the commission, handicapped as it was by lack of funds, to handle the enormous amount of documentary material which was required; third, the protection of the broadcasters against liability for unlicensed broadcasting until a suitable basis for the new licenses could be worked out; and, fourth, a complete new allocation of frequencies, power, and hours of operation for all of the existing 732 broadcasting stations to provide adequate local separation and a basis for the gradual elimination of distant interference.

Under the radio act of 1927 the Federal Radio Commission was formally organized on March 15, 1927, as follows:

Rear Admiral W. H. G. Bullard, of Media, Pa., commissioner from the second zone, chairman; Judge Eugene O. Sykes, of Jackson, Miss., commissioner from the third zone, vice chairman; O. H. Caldwell, of New York, N. Y., commissioner from the first zone; Henry A. Bellows, of Minneapolis, Minn., commissioner from the fourth zone; Col. John F. Dillon, of San Francisco, Calif., commissioner from the fifth zone.

Sam Pickard, chief of the radio division, Department of Agriculture, was engaged as acting secretary when the commission was organized. Mr. Pickard was made permanent secretary on April 20, 1927.

Assignment of Commissioners

Chairman Bullard took direct charge of the radio stations in the second zone, embracing Pennsylvania, Virginia, West Virginia, Ohio, Michigan, and Kentucky.

Commissioner Sykes took charge of the third zone, embracing North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Mississippi, Arkansas, Louisiana, Texas, and Oklahoma.

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Commissioner Caldwell took charge of the first zone, embracing Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Delaware, Maryland, District of Columbia, Porto Rico, and the Virgin Islands.

Commissioner Bellows took charge of the fourth zone, embracing Indiana, Illinois, Wisconsin, Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Missouri.

Commissioner Dillon took charge of the fifth zone, embracing Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Hawaii, and Alaska.

Due to the lack of funds, the commission was forced to open its offices at the Department of Commerce, where Secretary Hoover provided a suite of rooms formerly occupied by the Bureau of Navigation. It was possible to engage only a small office force, and it has been necessary to economize in every possible way.

When the Federal Radio Commission was inaugurated it found a chaotic condition prevailing in the radio field, for after Government control broke down in 1926 many broadcasters jumped their waves, seeking more desirable channels, regardless of their existing occupants. Even the channels reserved for Canada were appropriated, and split frequencies were used, with only a slight separation of from 1 to 5 kilocycles in many instances.

The problem confronting the commission was to try and bring order out of chaos by placing the 732 broadcasting stations on 89 wave lengths, so as not to create serious interference. The first act of the commission was to continue in force all radio amateur and ship licenses issued by the Department of Commerce and all coastal, point to point, technical, training, and experimental radio licenses, in order that attention might be concentrated on the pressing problems within the broadcasting band.

Public Hearings Helpful

For the purpose of providing opportunity for the presentation of general suggestions by the public and by qualified experts as to the methods for reducing interference within the broadcasting law, at its first meeting the commission arranged for a series of public hearings for March 29 to April 1, inclusive.

The subjects assigned for discussion were: Broadening the broadcasting band, limitation of power, reducing frequency separation, simultaneous broadcasting with the same frequency, chain broadcasting, division of time, consolidation of broadcasting service, limiting the members of broadcasting stations, and general discussion.

United opposition to widening the broadcasting band in order to accommodate more stations was expressed at the hearings by representatives of the radio art, science, and industry. Diverse views were presented regarding limitation of the power output, with the general opinion prevailing that this should be determ ned on the basis of area to be served by the respective stations. Stout opposition was registered also against reducing the frequency separation between channels from 10 to 7 kilocycles, while chain broadcasting in the main was indorsed. It was agreed that a division of time by stations is absolutely necessary to relieve to some extent the congestion on the ether channels.

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Modified Radio Law*

In 1928 the radio law of 1927 was modified by the 70th Congress in a further attempt to provide quality broadcasts for all, and particularly to provide equality in the different possessions, territories, states and zones, proportioned according to population, and to continue all of the authority of the Federal Radio Commission.[1]

Part II

Route of Radio Broadcast from Studio or Auditorium to Loud Speaker Showing Co-relation of Elements which Necessarily Function to Render Satisfactory the Sounds Emanating Therefrom

In the history of broadcasting development we must consider the route traversed by the modern broadcast to appreciate the steps of development and the obstacles that have been removed to bring out satisfying currents of musical frequencies of sufficient power from the present day radio receiver. For this purpose a chart entitled "Route of a Radio Broadcast" (Fig. 2) has been prepared. The route is mapped out through named squares connected by arrows, plain arrows for audio frequencies and feathered arrows for radio frequencies. Indicated by an asterisk at the bottom of the chart are listed the kinds of vehicles the broadcast uses many times in its journey. Also at the bottom of the chart, indicated by a dagger, are listed some of the causes of detrimental results which produce sounds unsatisfactory to the listener.

Broadcasters

In the upper left hand square of this chart we have portrayed the normal broadcasters. Broadcasters as here considered are complicated. They consist of wind instruments which have a sound pitch varying from 43 to 4608 sound cycles per second; stringed instruments which vary in pitch from 40 to 3072; the human voice which varies in pitch from 80 to 1,152, and the kettle drums which vary from 85 to 170. In addition we have harmonics of those broadcasters which may vary in pitch up to as high as 20,000. In the history of broadcasting development the first broadcasting by radio could not carry the human voice; all it could carry was code signals, short and long buzzing sounds. The second stage broadcasting could carry the human voice, but that was not sufficient for broadcasting as we now know it. The aim of broadcasting as we now know it is to carry faithfully music which has a range, as we will see by comparison in this first square, far

* See reference 74.

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ROUTE OF A RADIO BROADCAST

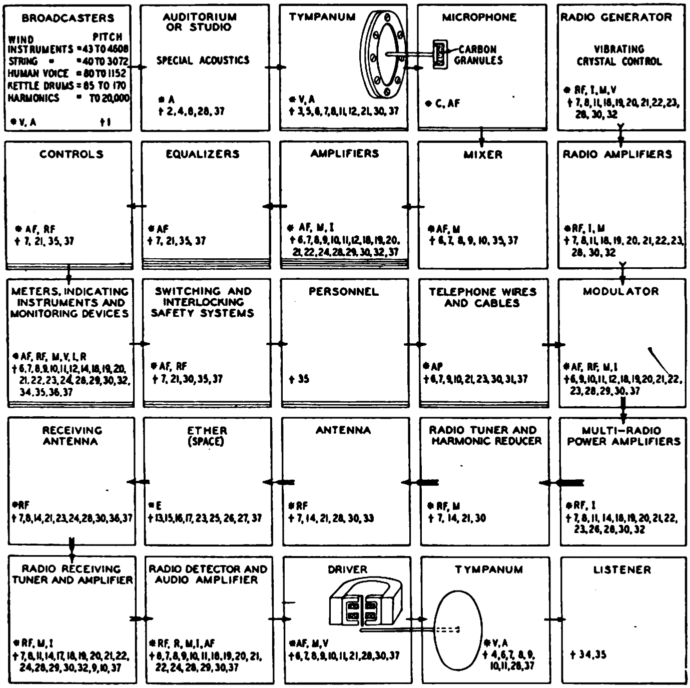

Fig. 2

* Broadcast Vehicles: A—air waves; V—vibrating solids; C—carbon compression and expansion; AF—pulsating or alternating audio current; RF—pulsating or alternating radio current; M—pulsating or alternating magnetism; I—pulsating electron stream; R—rectified current; E—ether waves. 2A, 5V, 1C, 30AF, 12RF, 25M, 25I, 1R, 1+E.

Results which have made broadcast reception unsatisfactory:
W—weakened or lost notes
E—exaggerated notes
D—distorted notes
D—added noises or notes
F—fluctuations

† Some of the causes of the above detrimental results:

1. orchestra characteristics (these may result in W, E, or D of the above unsatisfactory results)
2. sound reflection and absorption (W, E)
3. position of microphone (W, E)
4. sound phase interference (W)
5. damaged microphone (W, N, F)
6. audio-frequency discrimination (W, E)
7. loose parts (N, W)
8. natural periods (E, W)
9. non-uniform impedance (E, W)
10. non-uniform losses (E, W)
11. amplitude limitations (W, N, D)
12. over modulation (D, W, F)
13. radio fading and interference (F, W, N, D)
14. radio-frequency discrimination (E, W)
15. amateur stations (N)
16. government and commercial arc and spark stations (N)
17. oscillating receivers (N)
18. "A" battery faults (N)
19. "B" battery faults (N)
20. "C" battery faults (N)
21. poor connections (N, W)
22. tube noises (N)
23. power and light line disturbances (N)
24. regeneration (E)
25. station heterodyne (N)
26. harmonic heterodyne (N)
27. ratio of atmospherics and noises to broadcast (N, W)
28. detrimental mechanical capacity, magnetic and conductive couplings (N, D)
29. failing batteries (W)
30. leaking insulation (N)
31. induction to pick up lines (N)
32. "A," "B," and "C" battery eliminator variations (N)
33. shifting carrier wave (W, F, D)
34. listener's characteristics (W, E)
35. inexperience and inattention (W, E, D, N, F)
36. local interference and absorption (W, N)
37. cross talk (N)

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beyond the range of the human voice. It has been development along the lines of repeating all of the notes or pitches in such a range that has given us our present degree of quality in broadcasting transmission and reception. The broadcast of the winter of 1907 and 1908 was the "Merry Widow Waltz" played by a "His Master's Voice" phonograph into a telephone microphone. The microphone was in series with the antenna of the broadcasting station. The radio generator was the little arc. The listener with his crystal detector and head phones heard the tune of the music and some of the notes from that simple arrangement. Compare that with the complications of present day broadcasting.

The Studio or Auditorium

In this diagrammatic route of today's broadcasted pitches, notes, or audio frequencies, as they may be termed, they travel from the first square into the auditorium or studio which is provided with special acoustics including walls of special construction and including special movable wall drapes and floor coverings. Not only must certain fundamental notes and harmonics be produced at different strengths to make music satisfactory, but where that music is produced in a room a certain amount of reverberation is necessary. Reverberation is due to many reflections. It augments sounds and prolongs them. Part of the reverberation occurs in the auditorium or studio and part occurs in the listener's home. The amount that occurs in the studio, auditorium, or home depends on the walls, floors, and ceilings of the room and upon the number of people in the room. Also microphones must be so placed in the studio or auditorium that they are not at the focus of augmented notes or weakened notes or where they will be blasted by too much volume. With a definite microphone location the artists must be placed at proper relative distances and the acoustic drapes on the walls shifted to suit the number of people and the locations of the instruments. All of which makes the acoustics a complicated problem requiring considerable material and skill.

Tympanum

From the auditorium or studio the sound passes in air waves to the tympanum of a broadcasting microphone. While a broadcasting microphone appears to be about 6 or 7 inches in diameter as seen from the outside, the actual tympanum which picks up the energy from the sound waves in air is only a metal disk about 1-1/2 inches in diameter.

Microphone

The vibrations of that metal disk are transmitted to the actual carbon microphone in the next square through a short connection to

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the movable compression agent of the carbon microphone. There are, of course, other forms of microphones than carbon microphones, such as the condenser microphone; however, the carbon microphone is the most common form of microphone and is, therefore, the one indicated here. The microphone actually consists of two cells containing carbon granules, one on each side of the tympanum so that the carbon granules in one cell are being compressed while the carbon granules in the other cell are being relieved of compression through the vibration of the tympanum. This alternate compression and release of the mass of carbon granules varies the flow of a direct current which we will term "audio-frequency current." The microphone changes the sound waves to audio-frequency current.

Mixer*

That audio-frequency current passes downward to the next square marked mixer. The mixer is the device for bringing together the audio-frequency currents from several microphones. In the broadcast of music and speech it is sometimes necessary to use several microphones distributed at different points about the auditorium or studio in order to pick up a balanced output of sound or to make it possible to bring the various sounds to the mixer where they can be balanced by proper adjustments of the various elements in the mixer. All of this is done for the purpose of producing satisfactory sound quality for the listener.

Amplifiers*

From the mixer we pass to the next square, which is marked amplifiers. It will be noticed that this square and some of the other squares in the route contain more than one line at the bottom of the square. The multiplicity of lines at the bottom of the square indicates that the devices which those squares represent are used at more points in the route than are shown in this chart.

Amplifiers in this case and in this particular location mean audio-frequency amplifiers. Amplifiers consist of a succession of vacuum tubes which amplify the power successively, and those amplifiers are sometimes coupled together by transformers which may increase the voltage. To avoid distortion of sound frequencies amplifier tubes are sometimes coupled together by resistances or inductances which do not amplify the voltage but are simply serving as a means of coupling the output of one amplifying tube to the input of another tube.

Equalizers*

From the square indicated as amplifiers we next pass to the square indicated as equalizers. Equalizers are arrangements of conducting

* See reference 72.

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paths which make up for the loss of sound frequencies that has occurred in the preceding circuits, particularly if those preceding circuits have included comparatively long lines of conductors such as telephone wires and cables or complicated auditorium or studio wiring.

Controls*

From the equalizers we next pass to the controls which occur in several places in the route, and which in some cases are set more or less permanently, while in other cases they are continually operated by trained personnel. The extreme variation of power from music is often too great to be repeated along the route of a radio broadcast, particularly if that route includes long wire lines as in chain broadcasting.

For example the fainter sounds in a piece played by an orchestra may be weaker than ordinary voice power as used in speaking, or say less than five microwatts. A crescendo may be equal in power to five watts. The power ratio is a million to one, but to prevent the weak sounds from falling below the noises in wire lines and the loud sounds from being distorted in amplifiers it may be necessary to change the ratio of one million to one to a ratio of ten thousand to one. This is accomplished by an expert control operator who allows weak audio frequencies to pass along to the amplifiers and shunts off part of the more powerful audio frequencies so they are not amplified to the same extent before they reach the radio transmitter.

Meters, Indicating Instruments, and Monitoring Devices*

We next pass to the square which indicates the existence of meters, indicating instruments, and monitoring devices that are used at numerous points in the route both of audio frequencies and radio frequencies. By the use of such devices the personnel are able to manipulate the controls and re-adjust equalizers to preserve the music qualities of the broadcast.

Switching and Interlocking Safety Systems*

We next pass to the square which indicates the switch and interlocking safety system that is used at several points in the route and in connection with apparatus involved in the route to prevent errors and to make it possible to transfer rapidly from one broadcast to another, thereby contributing to the continuity of radio broadcasting for the better satisfaction of listeners.

Personnel*

In the next square is listed the word personnel for the reason that personnel is such an important element at many points in the broad-

* See reference 72.

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casting route. To make the devices repeat the broadcast satisfactorily and to make up for any obvious errors requires continual attention.

Telephone Wires and Cables*

In the next square is listed telephone wires and cables. In the subject of radio broadcasting the word radio appears so prominently that we sometimes overlook the fact that much of radio broadcasting is not in the handling of radio circuits and radio frequencies but is in the handling of audio circuits and audio frequencies. As we have shown in the first square, audio frequencies vary from about 40 to about 5,000 per second as fundamentals and have added to them a large number of harmonics which run to a higher value than 5,000, even to audible frequencies as high as 20,000. It is these harmonics that contribute what we call naturalness to sounds. In the route of radio broadcast there may be an almost unbelievable number of repetitions of audio frequencies. For example, a radio broadcast may be picked up, as it often has been, in Washington, D. C. where the United States Marine Band is playing and the President is speaking. Although it is picked up in Washington it may be broadcast from a broadcasting station in Seattle, Washington, in which case the broadcast actually travels from Washington, D. C. to Seattle, Washington, through the cables and wire lines of the telephone company. The common practice in the wire telephone transmission of these audio frequencies is to put them through amplifiers and equalizers very frequently in order to make up for the unequal transmission of the different audio frequencies by such wires and cables and to keep the broadcast music at a power level sufficiently above the noises that may be picked up by the wires along the line. These amplifiers and equalizers are used about every twelve miles in cable transmission, and at about every 250 miles in open wire transmission. Therefore, between such distant points as Washington, D. C. and Seattle, Washington, a great many equalizers and amplifiers have to be used in the attempts to reproduce good quality at the ultimate radio receiver.

It has probably been noticed by many that when broadcasts are picked up at a distant point the quality of those broadcasts as reproduced from a station is not so good as the quality of broadcasts which are picked up in the nearby studio of that station. That is largely because the transmission lines from distant points have, to some extent, damaged the quality of the broadcast more than the quality of the broadcast is damaged between the nearby studio of the station and the actual broadcasting station.

In nearly all cases at the present time, considering each high

* See reference 72.

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powered local broadcasting station, the actual broadcast is not picked up at the radio broadcasting station itself but is picked up at a studio or auditorium distant from the broadcasting station and comes to the broadcasting station through telephone wires or cables.

Audio to Radio

We now come to the radio power of the broadcasting system. All that has been said heretofore has related to the audio part of the broadcasting route. In modern high quality broadcasting stations, the audio frequency is not brought into contact with the radio frequency at the actual radio generator itself. That is one of the changes which has been made in recent years to improve the quality of the broadcast.

At first the audio frequency was brought directly to the radio generator, but it was found that the superimposing of the audio frequency on the radio generator circuit changed the radio frequency of the carrier. The radio-frequency carrier is the fundamental radio frequency of the radio generator. When the frequency of this carrier was changed the radio waves in travelling from the station to the broadcast receiver were also changed in frequency and produced a fluctuating or noisy effect at the radio receiver output.[55] To reduce the fluctuation in carrier frequency some stations under-modulate the carrier. That does not entirely cure the defect, and it produces a smaller music range relative to the nuisance range of the carrier. The separate radio generator with power amplifier has been under development since 1921, but is not as yet universally used.

Radio Generator and Radio Amplifiers

Therefore, the radio generator is indicated in the square at the upper right hand corner where the carrier radio frequency is generated and from which it passes to a square below where that one frequency is amplified through a succession of amplifiers. Thence it passes to the modulator and joins the audio frequencies. For holding constant the carrier frequency to prevent fluctuations and noises, to prevent heterodyne notes between stations on the same frequency, and to comply with the law, the radio frequency is controlled by a vibrating quartz crystal or checked against such a crystal frequently. Temperature-regulated crystal-controlled transmitters can now hold very accurately to their assigned frequencies.

Modulation

When the carrier radio frequencies and the audio frequencies join they produce, in effect, a number of radio frequencies equal to twice the number of audio frequencies.

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If the audio frequencies which have been brought from the studio cover frequencies from 40 to 5,000 or, we will say, a total of 5,000 cycles, then from the modulator a total of 10,000 radio frequencies and a carrier radio frequency pass to the next square, which we call the multi-radio power amplifiers.

Multi-Radio Power Amplifiers

As the name indicates, these are very powerful amplifiers designed to amplify the 10,000 or more radio frequencies.

Radio Tuner and Harmonic Reducer*

From these amplifiers we pass to the next square marked radio tuner and harmonic reducer by a large arrow indicating much more power. The purpose of this arrangement of circuits is to pass all of the 10,000 or more radio frequencies that are necessary for the production of higher quality audio frequencies for the listener, and to eliminate harmonics of the radio frequencies, more particularly harmonics of the carrier frequency which can produce interference in the reception of broadcasts from other radio stations. The radio harmonics are also confined by screening radio circuits and by the use of other harmonic absorbing circuits.

Antenna

From this square we pass to the antenna of the broadcasting station in which all of the radio frequencies are produced and which radio frequencies in turn produce waves that pass out in the ether indicated in the next square.

The Transmitting Medium

The ether or space does not always offer one constant path for all of these radio frequencies. Reflections frequently occur in the ether which jumble these radio frequencies so that the effect of some or all of them is decreased, producing what we call fading noises or simple fading that shows itself in a weakening of the received signal at the radio receiver. At a distance of 70 miles and over, every station fades as a rule. Sometimes the fading is noted even by the ear for shorter distances.

Receiving Antenna

Through the ether the waves arrive at the next square marked receiving antenna, in which they set up the 10,000 or more radio fre-

* See references 35 and 37.

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quencies and from which antenna or square we pass to the radio receiving tuner and radio amplifier.

Radio Receiving Tuner and Amplifier

The purpose of this tuner is to receive those 10,000 radio frequencies, and to exclude higher and lower radio frequencies from other stations. If that tuner and amplifier does not receive all of the 10,000 radio frequencies equally well or amplify all of them equally well, then the final output of music will be distorted. No transmitter or receiver is ideal to the extent that it handles all of the radio frequencies equally well in broadcasting and receiving the musical scale. Some of the most recent developments and one of the most recent tendencies is to so design the radio receiver and the radio transmitter that they will transmit the 10,000 or more radio frequencies more nearly equally well than they have in the past because they are obviously somewhat lacking in that respect and therefore even our best reproduction is lacking in fidelity for that reason.[38] At the same time there is a growing need for more selective receivers.

Radio Detector and Audio-Frequency Amplifier†

From the square of the tuner and amplifier we next pass to the square indicating the radio detector and audio-frequency amplifier. The radio detector is a rectifier which cuts off the upper or lower half of 10,000 or more of the radio frequencies carrying the 5,000 or more audio frequencies in which by doing so in effect changes those radio frequencies into approximately the original 5,000 or more audio frequencies. The audio frequencies are then amplified by the audio-frequency amplifier, which consists of a succession of two or more tubes coupled together by resistance coupling or transformer coupling. If the resistance coupling is used and carefully built it will couple the amplifiers together and transfer the audio frequencies without much distortion.[67] Up to within about the last two years transformers were commonly so constructed that they did not transfer the lower notes satisfactorily and due to capacity leakage did not transfer some of the high notes satisfactorily. Therefore, considerable distortion of the music was the result. The tendency now is to use high quality transformers and also to use tubes in the audio-frequency amplifier which can handle all of the current necessary to deliver a considerable amount of power in the form of more faithfully reproduced music. The tubes heretofore used have sometimes been limited in their ability to handle faithfully a considerable amount of power, therefore,

† See references 67, 68, 69, and 70.

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they distorted the output of the radio receiver. The use of better transformers and higher power tubes has produced a very noticeable increase in quality during the last two years.

Driver

Passing from the radio receiver we come to the driver of the loud speaker. The driver herein shown is what is usually called the balanced armature type. An armature is balanced between magnetic poles and the armature is surrounded by a winding which carries the output of a radio receiver, the audio frequencies from the radio receiver serving actually or in approximate effect to change the direction of the magnetism of the armature and cause it to alternate back and forth between the poles. The armature itself is a little rod of iron supported at its center on a torsion spring, and the results the device will reproduce depend somewhat upon the natural period of the torsion spring and the natural period of the iron armature. Also, the end of the armature is connected by stiff wire or rod into the next square where the other end is connected to a tympanum.

Tympanum

The tympanum is in contact with the air, and its movement driven by the movement of the armature moves the surrounding air, producing the sound heard by the listener. The output is more or less affected not only by the natural periods of the torsion spring, and the magnets and the armature, but is also somewhat affected by the natural period of the connecting arm and by the natural period or periods of the tympanum. If the armature is off center between the poles some rectification, distortion and false harmonics result.

Late 1927 and 1928 speakers use a different driver known as the dynamic type. This dynamic type was in use in the loud speakers of 1920 and 1921. It required powerful permanent magnets or an electromagnet which required power, making it comparatively expensive. In 1920 and 1921 it was attached to a flat or corrugated diaphragm or tympanum and horn. Now it is attached to a small conical diaphragm or tympanum and a baffel board or box. With the driving coil mounted directly on the diaphragm the vibrations of such solids as the torsion spring, the armature, and the connecting wire are eliminated.

Listener

In the next square we indicate the listener, who is the ultimate consumer of the broadcast. The original audio frequencies were produced and judged by ear, were changed to radio frequencies, then back

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to audio frequencies, and are now again judged by ear. The listener has become more and more critical of quality since 1922; he has had to learn a great deal. The ear is far from a perfect instrument.[63] Harmonics of a low note frequently give the impression that the low note is heard when it is not present.[62] The ear itself is a modulator.[64] These and other ear characteristics combined with lack of knowledge of what has caused distortions have caused many false impressions. But the listener still continues to learn; with increasing knowledge he requests better quality.

Broadcast Vehicles

The commonly used term for the main radio frequency of the broadcast transmitter is "carrier." That is, the main radio frequency of the broadcast transmitter is called the carrier frequency. Since in the transmission of a broadcast the carrier frequency is not the only thing that carries the broadcast, I have called the other things "vehicles." For example, in the studio the first "vehicle" is air waves, also from the loud speaker to the listener the last "vehicle" is air waves. At the microphone we have the vibrating solid tympanum, and in the driver and in the connections of the driver to the tympanum of the final loud speaker we also have vibrating solids. Therefore, vibrating solids are listed as a "vehicle." The standard frequency crystal of the radio transmitter is the pacing vehicle of the radio generator. In the microphone we also have carbon compression and expansion, which is one of the vehicles. The varying pressure in the carbon changes a current of electricity which may appear there and at other points as pulsating or alternating audio-frequency current. Therefore we consider pulsating or alternating audio current as another vehicle. In the same way the many pulsating or alternating radio currents which are used in the various radio stages of the radio transmitter system are considered as another vehicle.

In various couplings between audio-frequency circuits and in couplings between radio-frequency circuits the inductive method of coupling is frequently employed, in which case these frequencies are not current frequencies but are pulsating or alternating magnetic frequencies. Therefore, pulsating or alternating magnetism is considered as another vehicle. In the vacuum tubes we have a different form of current known as the electron stream, wherein electrons leave the hot filament of the vacuum tube and travel to the cold plate of the vacuum tube. This electron stream is termed another vehicle. Then at the radio receiver we have a detector producing rectified current, in which that process of rectification acts as another form of vehicle. Then, of course, we have the vehicle of the ether waves. All of these

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different vehicles are preceded by a key letter. *A*, for example, is for air waves, etc., which key letters are incorporated in the above squares indicating the place in these squares in which these various vehicles are used.

Following the list of vehicles at the bottom of the chart, we find the figures and letters, for example, 2-*A*, 5-*V*, etc. That is meant to indicate that in a normal broadcast these various vehicles may be used a considerable number of times. For example, in a normal broadcast 2-*A* indicates that air waves will be used twice; 5-*V* indicates that the broadcast will pass through vibrating solids 5 times; 1-*C* indicates that it will pass through carbon compression and expansion once. 30*AF* indicates that the broadcast is in the form of audio-frequency currents in wire circuits condensers, etc., as much as 30 times; 12 *RF* indicates that the broadcast is in the form of radio-frequency currents as much as 12 times in succession; 25-*M* indicates that the broadcast may be in the form of alternating or pulsating magnetism as much as 25 times in succession in the same broadcast; 25-*I* indicates that the broadcast may be in the form of electron streams as much as 25 times in succession in the same broadcast. 1 R indicates that the broadcast is detected or rectified once; 1 plus *E* indicates that the broadcast may be in one or more paths of ether waves at the same time in one broadcast.

Farther down towards the bottom on the left of this chart are enumerated some of the results which have made broadcast reception unsatisfactory in the past and which have through all these years been more or less gradually and partly eliminated. For example, the letter *W* indicates weakened or lost notes. The letter *E* indicates exaggerated notes. The letter *D* indicates distorted notes. The letter *N* indicates added noises or notes. The letter *F* indicates fluctuation.

Below that list are listed a number of the causes of the detrimental results just referred to. The list includes 37 causes which have in the past produced unsatisfactory output from the receiver, and which have had to be minimized or eliminated to bring broadcasting to its present degree of quality in reproduction. Following each of these numbered causes are letters in parenthesis referring to the results which have made broadcast reception unsatisfactory. For example, in the cause listed after 10, in the list of causes, we find letters (*E*, *W*). 10 indicates that a cause of unsatisfactory broadcasting is non-uniform losses; of the (*E*, *W*) the *E* refers to exaggerated notes, and the *W* refers to weakened or lost notes. They are the result of non-uniform losses. We find in the squares above that 9 appears in numerous

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squares. For example, in amplifiers and in the square marked telephone wires and cables. The losses in telephone wires and cables are greater for the higher audio frequencies than for the lower audio frequencies; therefore, the higher audio frequencies are weakened and the lower audio frequencies, considering the matter the other way, are exaggerated. This has been somewhat overcome, of course, by the use of equalizers and is being better overcome by improved equalizers. All of the numbered causes refer to the different squares showing where those causes have interfered in the past and in some cases where they interfere at present with the proper reproduction of radio broadcasts. The tendency of course has been, and still is, to remove those causes or to control them so that they cannot interfere with proper reproduction of broadcasts.

Part III

Possible Future Developments

The trend of past developments as indicated in the charts and their descriptions presumably points to some of the trends of future developments.

The trend from the beginning to the present has been to improve the quantity, variety, and quality of what the listener may hear, together with improvements in the convenience and appearance of the listener's apparatus.

Power

The effects of "static" or "atmospherics," the bugaboo of radio, have been the continual subject for elimination without appreciable success in broadcast reception. In broadcasting, their comparative effects have been steadily reduced by using more power at the broadcasting station, thereby riding over the static noises. Weakening of signals in daytime and summer has also been offset by using more power.

Fading at a distance of seventy miles or more has gradually come to be a recognized characteristic in broadcasting. By the use of more power at the stations, and recently by the use of automatic volume controls, the intelligibility of broadcasts have been improved. Those things indicate that more power will probably be used in the future.

The continual increase of power used by broadcasting stations from year to year is one of the conspicuous features of broadcasting development.

At present the average broadcasting station power is nearly 2 kw. If the increase should continue as in the past the average might be 10 kw and the maximum power might be 500 kw in less than five years.

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Both broadcasters and broadcast listeners ask for more power. The broadcast listeners ask that their favorite stations be given more power so that more satisfactory results may be obtained. The broadcasters ask for more power so that more people can get satisfactory results from their stations, thereby influencing more people to listen to them.

There is more to recommend great power and increase of power for stations in cleared channels than for stations operating in the same channel with other stations. However, when stations in the same channel are brought to so nearly the same frequency that heterodyne squeals are not heard, or are not disagreeable, the increase of power in these channels may be less objectionable.

Where stations on the same frequency are operated on the same program, as they may be in the future, still more power can probably be used with less objectionable features than now exist with weak stations on the same frequency.

Altogether it seems that the predominant natural demand and possibilities point toward more power both as to average power and as to maximum power.

Selective Receivers

Related to the amount of power and number of stations, as indicated by the curves, is the matter of cross-talk. Fig. 2 also indicates the places in the route where cross-talk exists.

One kind of cross-talk has existed because one microphone picked up what happens in two studios, or the wires from studios were unintentionally coupled together and fed two programs to one broadcast transmitter. Such cross-talks have been decreasing, and it is expected that they will be almost entirely eliminated.

The other more common and detrimental kind of cross-talk occurs in the ether or space as the number or power of stations is increased. The extent to which such cross-talk comes from the listener's loud speaker depends upon the locations of the broadcasting stations relative to the listener, and upon the selectivity of the listener's receiver as modified by the frequencies and powers of the stations when the listener has his receiver tuned to a station on a cleared channel. Other complications, such as the peculiarities of the listener's locations, the time of day, and time of year, enter into those matters.

When the listener is tuned to a station that is transmitting on the same frequency on which other stations are transmitting, the cross-talk possibilities may be further complicated, depending on his location.

There are over 600 broadcasting stations, about 5,000,000 square

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miles of non-uniform territory, and over 50,000,000 listeners involved in this. The listeners in rural and metropolitan United States and Canada want cross-talk reduced.

Since 1922 the Department of Commerce and the Federal Radio Commission have tried to reduce such cross-talk to a satisfactory minimum by changing the locations, frequencies, and relative powers of broadcasting stations. The continued results indicate that such cross-talk cannot be reduced to a satisfactory minimum by such methods. Something else evidently must be done. It is apparent that more selective receivers are required. The cross-talk is bound to be in the ether or space; receivers that will select what is wanted are required.

Cross-talk between stations in the same channel must be reduced to as satisfactory minimum as is possible by regulating the power and location of stations or by synchronizing the stations on the same broadcast, but the cross-talk from stations on other channels is evidently chiefly the problem of receiver manufacturers.

The background of past development and present conditions indicate that the receiver of the near future should be a very selective bandpass receiver. From this consideration of the past and present, it appears that the responsibility for cross-talk between channels will lie principally with the manufacturers of receivers, and that cross-talk will be greatly reduced or eliminated by them.

Measurements

The trend of development has repeatedly brought up such questions as what is effective power and what is service range, indicating the need for better standards and more measurements locally and at distances. That condition should prophesy the wide extension of volts-per-meter and other measurements.

Harmonic Reduction

The power increases in broadcasting and the expansion of radio to the higher frequencies have pointed out the necessity for eliminating harmonic radiation. The indications now are that such harmonics can and will be materially reduced.

Audio Engineering

It is a conspicuous part of the development indicated in both charts and in their descriptions that radio broadcasting is a part of radio engineering, wherein audio engineering is very important. A radio broadcast is first audio, then radio, and then audio. For future improvement the audio must improve as well as the radio.

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In that connection, it is interesting to our members to note that the word "audio" as applied to frequencies and engineering was coined and standardized by the Standards Committee of this Institute in 1913.

The Microphone and Loud Speaker

From the very beginning of broadcasting efforts have been made to improve the input microphone and yet that device, although still in need of improvement, has probably changed less than any other element. The terminal device, now the loud speaker, a powerful counterpart of the microphone, has not improved as much as expected. That history may indicate some future radically different audio devices to take their places.

More Channel Space for Audio Frequencies

Running through the chart Figs. 1 and 2, is continued development to produce "quality" or "fidelity" or "faithful reproduction" for the ear of the listener. That trend of development may be expected to continue.

Part of our available music, to be natural and satisfactory, must contain harmonic frequencies that are higher in frequency than 5,000 cycles. When audio frequencies above 5,000 cycles are broadcast from a station the radio-frequency band of that station is over 10 kc wide, therefore that station's radio frequencies encroach on the next channel to produce cross-talk. Therefore, the desire and effort to produce higher quality may result in an effective demand for widening the channels.

To widen the channels has become more and more difficult in recent years of broadcasting development, due to the increase in radio uses below 550 and above 1,500 kc, and due to the demands for places on the existing 10-kc channels.

This condition may result in the often talked of single-sideband and carrier transmission which only requires a band width about equal to the highest audio frequency that is transmitted, instead of twice that frequency as at present. Such single-sideband and carrier transmission would have room in the present 10-kc channels to carry as high as the second harmonic of the highest fundamental frequencies in music.

Reduction of Heterodyne Interference

Through all radio broadcasting development and other radio development, accurate and stable frequencies have been a goal that has been steadily approached. In 1913, it was considered a laboratory

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feat to measure a frequency to within 0.5 of 1 per cent and frequencies were only required to be exact to within about 10 per cent. Now radio laboratories claim to be able to hold frequencies to 0.00002 of 1 per cent, and broadcasting stations claim to be able to hold their frequencies to 0.001 of 1 per cent or better.

The time has apparently arrived when it is practical for broadcasting stations to hold their frequencies to within 50 cycles of a given frequency, and the time has also apparently arrived when the government checking agencies are capable of checking such frequencies sufficiently accurately and fairly rapidly in any part of the United States through the Bureau of Standards equipment and the checking equipment of the Radio Division of the Department of Commerce in its several districts.

This situation of being able to hold and check frequencies accurately, and the development within the recent years of high modulation seemingly predict the elimination of heterodyne squeals that have been characteristic in the channels where two or more stations are transmitting in those channels.

High modulation reduces the heterodyne or nuisance range of a station relative to its service range. In effect, that can mean the reduction of the strength of the heterodyne.

Holding two stations in a channel to within 50 cycles of the same frequency means that the heterodyne note will be lower than 100 cycles. The audio-frequency circuits of radio receivers and the loud speakers are usually comparatively inefficient at such low frequencies and the ear is not sensitive to such low frequencies,—therefore such low heterodyne frequencies are far less disturbing in effect than have been the irritating heterodyne squeals.

Since over half of the present broadcasting channels are occupied by more than one station at a time and since over 80 per cent of the stations are in those channels, decreasing and eliminating heterodyne disturbance in those channels would be a high percentage improvement of great advantage to the broadcaster and to the listener.

Speculative Possibilities

Relay broadcasting, using for example high frequencies to reach great distances with a minimum of atmospheric interferences and a multiplicity of such frequencies to balance fading effects, whereby a broadcast might be sent around the world and be picked up for rebroadcasting by local stations, has been foreshadowed to some extent in the development up to the present.

Broadcasting of moving pictures to some extent is prophesied

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from the results of past developments. Even the transmission of talking pictures is prophesied. Considering the limitations to available wavelengths that have been developing, it seems that the most practical method would be in taking the moving pictures rapidly, transmitting them more slowly, and then reproducing them rapidly.

Opportunity to Promote Rapid Development

Fig. 1 indicates the continual demand for more broadcasting stations. The number of stations continually increased in the past except where they were curbed by the Department of Commerce and later, after that curb had failed, were curbed by the Federal Radio Commission.

Between the failure of the curb by the Department of Commerce and the establishment of the Commission there was a decided increase.

Although the curb on increase by the Commission has been in effect for two years and should be well known, daily attempts are made to add other broadcasting stations. If that curb was suddenly removed there might be as many as 3000 applications for stations within 30 days.

The demand for more broadcasting stations and the desirability and undesirability of more broadcasting stations can be discussed in more ways than we have space for. However, I would like to bring out one point as to how that demand should affect broadcasting.

The demand for more stations may not result in many more stations, but it may result in continuous and comparatively rapid improvement of the stations that are permitted to broadcast. In other words, it may work out that the broadcaster will be required to make his station as good as possible, or get off the air, and let somebody on who will make a good station.

If the demand is viewed and acted upon in that light, then we may expect it to produce better broadcast engineering and better programs.

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25	Wireless Telephony (on U. S. S. Conn.)	*Electrical World*			1907	Oct. 12th	710
26	Wireless Telephony (Purchase of DeForest Phones by Navy)	*Electrical World*			1907	Oct. 26th	799
27	Practical applications of Wireless Telephone (DeForest phones on Naval Vessels)	*Electrical World*			1907	Nov. 9th	926
28	New Telephone Patents (loud speaker articulation is not good because of abnormal excitation of diaphragm)	*Electrical World*			1907	Nov. 9th	926
29	Wireless Telephony before the N. Y. Elec. Society (DeForest speech)	*Electrical World*			1907	Nov. 30th	1034
30	Recent Improvements in the Production of Undamped Oscillations, by J. A. Fleming	Book, The Principles of Elec. Wave Telegraphy			1908 *Edition*		644
31	Power of Fundamental Speech Sounds, by C. F. Sacia and C. J. Beck	*Bell System Technical Journal*	5		1926	July	393
32	Methods of High Quality Recording and Reproduction of Music and Speech based on Telephone Research, by J. P. Maxfield and H. C. Harrison	*Bell System Technical Journal*	5		1926	July	493
33	A High Efficiency Receiver for a Horn Type Loud Speaker of Large Power Capacity, by E. C. Wente and A. L. Thuras	*Bell System Technical Journal*	7	1	1928	Jan.	141
34	Power rating of Broadcasting Transmitter, by O. M. Glunt	*Bell Laboratories Record*	5	3	1927	Nov.	69
35	The Fifty Kilowatt Radio Transmitter by A. W. Kislspaugh	*Bell Laboratories Record*	5	3	1927	Nov.	71
36	Telephoning Radio Programs to the Nation, by L. N. Stoskoff	*Bell Telephone Quarterly*	7	1	1928	Jan.	5
37	3XN Bell Telephone Lab. Jan. 9, 1928	Special for I. R. E. 1928 Convention					
38	On the Distortionless Reception of a modulated wave and its relation to selectivity, by Frederick K. Vreeland	Proc. I. R. E.	16	3	1928	Mar.	255
39	The Audion—Detector and Amplifier, by Lee DeForest	Proc. I. R. E.	2	1	1914	Jan.	15
40	Some Recent Developments in the Audion Detector, by Edwin H. Armstrong	Proc. I. R. E.	3	3	1915	Sept.	215
41	The Measurement of Acoustic Impedance and the Absorption Co-efficient of Porous Materials, by E. C. Wente and E. H. Bedell	*Bell System Technical Journal*	7	1	1928	Jan.	1

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42	Notes on the Design of Resistance-capacity coupled amplifier, by Sylvan Harris	Proc. I. R. E.	14	6	1926	Dec.	750
43	Tuned Radio Frequency Amplification with Neutralization of Capacity Coupling, by Louis A. Hazeltine, March 2nd, 1923	*Proc.* of the Radio Club of America	2	8	1923	Mar.	
44	Westinghouse radio receiver advertisments..	*QST*			1921	Sept.	118
45	Schedule of Radiophone Station	*QST*			1921	Dec.	33
46	Westinghouse receiver and horn—loud speaker advertisment	*QST*			1922	Jan.	101
47	Practical Radio Amplification, by Robert L. Higgy	*QST*			1922	Feb.	35
48	The Radiophone and the Code Station. An argument for cooperation, by R. S. Kruse	*QST*			1922	Mar.	21
49	Getting Started Listening	*QST*			1922	May	12
50	Rotten Broadcasts	*QST*			1922	May	12
51	A Giant Horn Speaker	*QST*			1922	July	54
52	The Voluntary Lid	*QST*			1922	Nov.	44
53	Performance and Theory of Loud Speaker Horns, by A. N. Goldsmith and John P. Minton	Proc. I. R. E.	12	4	1924	Aug.	423
54	Design of Telephone Receiver for Loud Speaking Purposes, by C. R. Hanna	Proc. I. R. E.	11	4	1925	Aug.	437
55	Some Studies in Radio Broadcast Transmission, by Bown, Martin, and Potter	Proc. I. R. E.	14	1	1926	Feb.	57
56	The Shielded Neutrodyne Receiver, by Dreyer and Manson	Proc. I. R. E.	14	2	1926	Apr.	217
57	Recent Development of Radio Telephones, by Walter S. Lemmon	*Proc.* of the Radio Club of America	1	4	1920	June	
58	Eighteen years of amateur Radio, by Geo. E. Burghard	*Proc.* Radio Club of America (and in *Radio Broadcast*)	2	9	1923	July	
59	Fundamentals of Loud speaker Construction, by A. Nyman	*Proc.* Radio Club of America (also in *Radio Broadcast*)	2	12	1923	Oct.	
60	Cone Loud Speakers, by C. L. Farrand	*Proc.* Radio Club of America (*Radio Broadcast*—October, 1926)	3	10	1926	Oct.	
61	A Fundamental Analysis of Loud Speakers, by John F. Nielson	*Proc.* Radio Club of America	4	1	1927	Feb.	
62	Physical Criteria for determining the Pitch of a Musical Tone, by H. Fletcher]	*Physical Review*			1923	Sept.	

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63	Physical Measurements of Audition and their bearing on the Theory of Hearing, by Harvey Fletcher	*Journal* of the Franklyn Institute	196	3	1923	Sept.	
64	Auditory Masking and Dynamics of the inner ear, by R. L. Wegel and C. E. Lane	*Physical Review*			1924	Feb.	
65	A New System of Short Wave Amplification, by E. H Armstrong	Proc. I. R. E.	9	1	1921	Feb.	3
66	Long Distance Wireless Telephony, by R. A. Fessenden	*Electrician* (London)	59		1907	Oct.	985
67	Loud Speaker Testing Methods, by I. Wolff and A. Ringel	Proc. I. R. E.	15	5	1927	May	363
68	Audio Frequency Transformers, by John M. Thomson	Proc. I. R. E.	15	8	1927	Aug.	679
69	Notes on the Testing of Audio Frequency Transformers, by Edward T. Dickey	Proc. I. R. E.	15	8	1927	Aug.	687
70	The Testing of Audio-Frequency Transformer-Coupled Amplifiers, by H. Diamond and J. S. Webb	Proc. I. R. E.	15	9	1927	Sept.	769
71	Interference, by R. H. Marriott	Proc. I. R. E.	11	4	1923	Aug.	375
72	Broadcast Control Operation, by Carl Dreher	Proc. I. R. E.	16	4	1928	Apr.	498
73	Annual Report of the Federal Radio Commission	U. S. Government Printing Office	Year ended June 30, 1927				
74	Ditto	Ditto	Year ended June 30, 1928 and supplement to Sept 30 1928				

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Proceedings of the Institute of Radio Engineers
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Discussion on
RADIO DIRECTION-FINDING BY TRANSMISSION AND RECEPTION*

(R. L. Smith-Rose)

Stuart Ballantine:[1] Dr. Smith-Rose's use of the reciprocity theorem and critical discussion of its validity in connection with the "night effect" interested me very much as I have often had occasion to put it to the same use. As a point of minor criticism I should like to point out that in the form in which this theorem was originally given by Sommerfeld[2] and in which it has been reproduced in this paper by Dr. Smith-Rose, it cannot be legitimately applied to direction-finding systems. Sommerfeld's statement was that if an antenna A_1 radiated a certain average power and was received by a second antenna A_2, the electric force at the receiving antenna would be the same as it would be if observed at A_1 with A_2 radiating the same power. J. R. Carson has recently pointed out to me that this statement is valid only for antennas in free space (e.g., at a considerable distance from all conductors such as the earth) which behave as simple dipoles. Carson's criticism is just and the correct statement, as given by him,[3] is as follows: If an impressed force acts in a branch of an antenna A_1 and the current in a branch of a second receiving system A_2 is observed, this current will be equal to that which would be observed in A_1 with an equal impressed force acting in A_2. In this form the theorem is applicable to the direction-finder system. Fortunately, the conclusions of Smith-Rose's paper are not affected by the use of Sommerfeld's theorem, and are obviously supported by the proper theorem.

This theorem is particularly useful in thinking about direction-finders and may perhaps be employed to explain some of Dr.Smith-Rose's difficulties with the obscured minima which he observed with the rotating beacon installation. According to the reciprocity theorem the signal received on a vertical antenna from a rotating transmitter coil is precisely the same as that which would be received by the coil if the vertical antenna were transmitting. From 1917 to 1920 I had the opportunity, while engaged in the development of the rotating coil radio compass for the U.S. Navy, of studying the latter situation in some detail. It was discovered that the environs of the coil, refraction at the coastline, currents on land lines, and so forth, destroyed the simple plane wave from the transmitter and produced at the coil an elliptical rotating field (magnetic). When you rotate a coil in such a field the signal does not disappear but merely goes to a minimum. I found that the minimum could be cleared by deriving an e.m.f. of proper phase from the antenna action of the coil by means of an artificially produced electrical unbalance of the capacities to ground, and neutralizing the residual signal by this e.m.f. The device used for this purpose was called a "compensator," and was independently invented in France at about the same time (1917) by Commandant Rene Mesny. The amount of unbalance required for perfect compensation was found to vary with the azimuth. It should be remarked for those who have not had the opportunity of specializing in this subject, that compensation simply clears the minima of signal and permits accurate bearings to be taken; it has nothing to do with the elimination of the "deviation" or azimuthal error of the compass, which is due to the part of the field in phase and is generally unaffected by compensation. The deviational errors are generally evaluated by calibration.

* Proc. I. R. E., **17**, 425; March, 1929. Presented before New York meeting of the Institute, February 6, 1929.
[1] Boonton Research Corporation, Boonton, N. J.

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The important point here is that the amount of compensation required for a perfect minimum varies with azimuth. In the case of an installation on a battleship the variation is considerable, so great in fact that we found it desirable to actually use an auxiliary antenna for the compensating e.m.f. rather than to depend upon the relatively feeble antenna effect of the coil. In the case of an installation on flat homogeneous land free of surrounding conductors, the compensation required is not only small but varies little with the azimuth; nevertheless some variation is generally present in the ordinary land sites.

We may conclude from the reciprocity theorem that if we find it necessary to have a compensator on a recieving loop which varies with the azimuth, we must do the same thing when using the loop as a transmitting beacon and receiving the signals on an ordinary vertical antenna; otherwise the minima will not be clear at all azimuths. I did not understand from the paper that such arrangements had been made. I wonder if Dr. Hull had any conversations with Dr. Smith-Rose on this point.

L. M. Hull:[4] Yes, I believe there was a definite attempt to vary the compensation. It was not mentioned in the paper. It was automatic in this sense; that it was carried out by varying the spacings of the various wires which were strung up around the loop, to produce an antenna effect which varies with the azimuth. Dr. Smith-Rose told me that although he thought the idea was good, the work had not been carried to a successful conclusion.

Stuart Ballantine: It seems to me that the necessary variation of compensation could be secured by means of some mechanical contrivance, such as a cam system, similar to those we used with the receiving coils.

It is of course understood that all this relates to ordinary transmission in the absence of night effects. This is perhaps the most important condition.

A. Hoyt Taylor:[5] I take it that the reciprocity theorem was called upon by the author merely to support his claim that the "night effect" would produce similar types of errors and of the same order of magnitude by either the transmission by beacon or reception by loop, and I believe that particular conclusion is unaffected by Mr. Ballantine's criticism, except possibly the magnitude.

Stuart Ballantine: It may also be remarked that the same deviations that would be observed if the rotating beacon transmitter were used as a receiver will be present when it is used as a transmitter. This would seem to require the calibration of the station and publication of the necessary corrections. According to our experience with the fifty or sixty coastal radio compass stations which were erected from 1918–1920 by the Navy these deviations (maximum values) may range from 1–10 deg., depending upon the site.

A. Hoyt Taylor: It is, of course, possible that the British experiments were nearly always made under conditions as nearly ideal as possible; that they just failed to reach idealism in the case of the installation of that loop by having a different radiation resistance in one direction than in the other owing to the proximity of the water on one side and not on the other. That alone may have caused small changes which would account for the beacon variation, because they apparently did not have a master oscillator transmitter. We know from work we have done that we would have to be extremely careful of coupling with

[2] *Jahr. der Draht. Tel. und Tel.*, **26**, 93, 1925; Ballantine, Review of Current Literature, Proc. I. R. E., **16**, 513; April, 1928.
[3] Proc. I. R. E., **17**, 952; June, 1929.
[4] Radio Frequency Laboratories, Boonton, N. J.
[5] Superintendent, Radio Section, Naval Research Laboratory, Bellevue, Anacostia, D. C.

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any nearby conductors. The question is whether we are dealing with variations of the transmitter or of the received signal.

I might mention one or two things that occur to me. One is that the thing which is most difficult to get rid of in the way of direction-finding error is the so-called "night effect." Personally, I don't like that term at all because it occurs altogether too frequently in the daytime. I believe I was one of the original discoverers of it, and it is true that I discovered it at night, but it is due to components of the wave coming down from the Kennelly-Heaviside layer with horizontal electric polarization. This can occur during the daylight hours also, so I hope you will get another term for this than "night effect."

It might be well to analyze very briefly the conditions under which we may expect the "night effect" to occur. For want of a better word, we will continue to call it "night." Evidently when your incoming radiation arrives at a low angle with the horizon, the state of polarization will make very little difference in your compass reading. Suppose a wave is arriving from a horizontal direction; then if your loop is set squarely across that oncoming signal with a minimum for the vertical component, the horizontal components will also cancel out. It is only then when the horizontally polarized component has a velocity in the vertical direction, which means only when the wave comes in at an angle with the horizontal, that you get this effect.

If we look over the radio-frequency spectrum, we can, I think, draw certain conclusions as to when we may expect this "night effect," so-called, to be most aggravated. Without going into the reasons for it, we may say that on very long-wave reception we have excellent reasons for believing that the major portion of the energy arrives at relatively small angles with the horizontal. The angle of "come down" is not very far from the horizontal. According to that, bearings taken on long-wave transoceanic stations should show relatively small errors of this type. The fact is that they do show enormously smaller errors than the same stations will show at moderate distances. At distances of 100 miles or so, you get this effect at a maximum for long-wave stations, because the energy which has come down from the layer arrives at a relatively high angle with the horizontal. Such polarization as exists in the horizontal plane therefore has a strong component of its velocity in the vertical. Thus we find that the short distance long-wave stations, as borne out by the curves that were presented here, have the greatest errors due to this cause. Frequently, complete reversals or complete rotations of 360 deg. occur, as I myself observed in the winter of 1919, and so reported, incidentally, with the correct analysis of the cause of this as being due to polarization.

Suppose we go to the other extreme of very high frequency. Supposing we go up to 20 megacycles. Under every condition that we have been able to analyze excepting some rather special but not very frequently occurring cases, we find that 20-megacycle transmission from a distance also arrives at relatively low angles, generally 10 to 20 deg. from the horizontal. We might infer from this that here also would be a region where we might hope to get very good bearings, but such is not necessarily the case. In the case of very long waves arriving at a low angle, it is practically impossible for a horizontal polarization to progress along close to the surface of the earth for any considerable distance without that horizontally polarized component being completely absorbed, but in the case of a very short wave it is possible for this component to come a long distance and actually arrive at our receiver, because the antenna structure is a

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much larger fraction of a wavelength above the earth. So the two extremes of the spectrum give us under ordinary conditions low angle, good direction-finding, but at the high end of the spectrum there is still much difficulty from horizontal polarizations because it can exist and follow along with the wave even when it is only a few feet above the surface of the earth. Short-wave horizontal polarizations are also more readily reflected from the surface of the earth and the water, and so we have difficulty even with the low-angle stuff on the very high frequencies, though not as much difficulty by any means as we have with the fairly low frequencies and the fairly high angles.

Another point is as to the minimum distance at which you can get these so-called "night effects." I don't agree with the paper as to this minimum distance. It cannot be stated definitely because it is quite evidently a function of the normal range of the ground wave to the station, and that in turn is a very decided function of the frequency on account of the variable absorption of the ground wave; so that that is a matter depending entirely upon the frequency of the transmission and varying according to more or less well-known laws. We can say in general that the "night effect" will be small when we are within the normal ground wave range of the station and the ground wave predominates against the sky wave, and we get fairly good minima, with blurrings of the minima here and there due to a little sky wave.

I do not agree with Dr. Smith-Rose's statement that in the broadcast band large errors are seldom noticed at the distance mentioned in his paper, because I have personally observed variations as high as 30 deg. On a well compensated loop functioning on WRC in Washington at a distance of less than six miles, they don't occur very often, but we do occasionally during the dark hours get large deviations of apparent direction with a simple loop. I imagine those conditions vary a good deal in different parts of the world.

There is one thing I would like to bring out a little more fully than Dr. Hull did, in regard to the Adcock system. The Adcock system is as much less sensitive in pick-up, roughly speaking, than the ordinary loop, as the loop itself is than the ordinary antenna; in other words, it is a differential on the signal from two dipoles, or two doublets, as we call them nowadays, which would perfectly neutralize each other, except that the vertical component of polarization has a phase difference from one direction to the other, and it is only by virtue of that difference in phase—a geographical phase difference if you please—that we get any signal at all. It means, therefore, that to get the best results on the Adcock system we shall have to do exactly what we did in the old days, which I am sure Mr. Ballantine will well remember, when we tried to adapt ordinary receivers, such as had been giving good service on vertical antennas, to loop reception. We had to have recourse to various expedients, such as oscillating receivers on spark reception with a horribly bad note, in order to make them sensitive enough to function on a loop. Radio receivers—thanks to amplification, and so forth—have been tremendously improved so that ordinary loops, even in aeroplanes, are capable of giving us really tremendous signal strengths, but it looks now as though again we shall have to go very much further in receiver sensitivity in order to get the best possible results with the Adcock system. The system itself is, in my opinion, decidedly the best thing there is for eliminating the horizontal component of polarization and permitting a bearing on the vertical components alone.

Dr. Hull pointed out that there was difficulty in attaining the requisite sensitiveness on the very long waves. For the intermediate band of frequencies

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he stated that they had carried out a great many experiments, probably because they were able to use the superheterodyne principle or something of that sort, to obtain a very high degree of amplification.

One place where we need this Adcock system more than anywhere else is in the high-frequency band. Unfortunately, receiver design is somewhat up in the air today as to just what we shall do to get the necessary multiplication of ten or one-hundred fold in sensitivity, which you ought to have to get first-class results with the Adcock system in the very high-frequency band. It is a problem that radio engineers ought to be thinking about. Because you have high-frequency receivers which will pick up all kinds of disturbances, like automobiles and aeroplanes at several miles' distance, doesn't mean you have enough yet to give us the best we need for this type of directional work. You must remember that the sensitivity of such a proposed receiver would be low to disturbances as to actual signals, so that the signal ratio would not be unduly increased by the higher sensitivity over what we have in the higher frequency receivers today.

There is one other matter upon which I believe I differ a little from the author. He refers in one place to the proposition that it is quite generally believed that radio energy mostly travels along a great circle connecting the transmitter with the receiver. Well, I think it is generally conceded for almost the entire radio spectrum that most of the energy does travel along a great circle distance connecting the transmitter with the receiver, but certain scattering effects are being observed these days. Certainly what we know of the Kennelly-Heaviside layer and its perturbations would indicate the extreme likelihood of lateral deviations of the sky wave which will permit them to come in from really different directions than the true bearing or great circle bearing of the transmitter, so that instead of stating, as the author does, that deviation from the true great circle bearing is not to be worried about until we get above 6000 kc, I would be rather fearful that it might have a considerable influence on conditions even at 1000 kc. I have an idea that the choice of system, in this country at least, is going to work out with the preference for ship navigation in favor of having the compass on board the ship, but for commercial air navigation it is probably going the other way, with a preference in favor of the beacon system because of the simplified radio gear which the aeroplane can carry under those conditions. I believe, however, that it will be a long time before our standard coastal station installations will be abandoned. They will probably be used for many years to come.

There is one point that I would like to see discussed further. When I did that work in the Navy back in 1919 on so-called "night errors," we concluded that the region of 375 kc was about ideally located for radio compass work because at the normal ranges where you would be called upon to take compass bearings, between 100 and 200 miles, the sky wave effect is not very large compared with the ground wave effect, and so fairly good bearings are generally possible. We actually examined continuous wave transmission down to 900 meters and we found even on continuous waves less error from horizontal polarization on that wave than we did on much longer waves. Practically all of the experiments made by the Navy and by the Army showed a much larger error on CW transmissions than they did on spark transmissions, and we attributed that to the breaking up of phase relations and the failure of the phase angles and polarization angles to hold definite sequence so as to form a definite pattern at the loop. What the so-called "night effect" would do with the spark signal was

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merely to blur the minimum, but not distort it enough as in the case of CW where you could have definite patterns produced with sequence of phase. That conclusion was confirmed by some of the earlier English work, I believe, where they made some comparisons between ICW and CW, but I note that Dr. Smith-Rose says that there is no practical difference between bearings as obtained by continuous wave and by interrupted wave. That statement seemed so contrary to what we actually obtained in practical tests, and to the earlier general opinion on that subject, that I should like to be further informed about that. Perhaps Dr. Hull had some conversation about that with Dr. Smith-Rose.

L. M. Hull: I have nothing further on that point, except that I can state that this view was very definitely corroborated by Dr. Smith-Rose's answer to a question which I asked him on that point.

A. Hoyt Taylor: I think that was very curious because we did quite a lot of work on spark signals as compared with CW and we thought we observed a very definite difference between the two and the Army's work by Kinsley up at Houlton, Maine, on the spark signals used in Europe or on Arlington signals—the old spark signals with which you set time with the 100-kw spark set— gave the same result, and also some work that the Army did down on the Mexican border on Mexican stations that they were observing down there in the 5000-meter band gave similar results. So that it doesn't seem quite logical to me that there should be no difference at all between the two methods. I should expect the ICW signals, where the phase relationship was interrupted from time to time, to show quite a difference. I wouldn't expect much difference on modulated CW but on isolated or interrupted CW, I would expect it.

Lester Jones:[6] With respect to directional variations with radiation on spark signals and ICW signals, I have the impression that a probable partial explanation for it is the following: Where observations were made on spark signals the receivers had to be adjusted to a lesser degree of sensitivity because the spark transmitters generally put out more energy than the ICW transmitters. Where the receiver is more sensitive, as with ICW there is more possibility of having variable feedback between receiver and loop. This would give rise to a variation of sensitivity in the receiver and would introduce a slight error which would be variable depending upon the position of the operator's body and the exact amount of regeneration used in the receiver. I would give a little more shift to the ICW system than to the spark system.

In one of the tests I made, care was taken to eliminate all traces of reaction from the receiver to the loop, which completely eliminated the possibility of this secondary error. This showed that there was no difference between spark and ICW direction shifts. I remember in the beginning of our tests it was very easy to get a secondary error on account of residual feedback from the rotating loop.

A. Hoyt Taylor: I didn't mean to state that there was a difference between ICW and spark but rather between ICW and pure CW.

Stuart Ballantine: We made some experiments during 1919, independently of those of Dr. Taylor, which were intended to compare the reliability of CW and "spark" signals for direction-finding purposes at 800 meters. Our results agree in general with the experience cited by Dr. Taylor, in that the average variations with spark signals (500-cycle quenched gap transmitters) were nearly always less than those observed with CW signals. The observations were

[6] Technidyne Corporation, New York, N. Y.

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made at the radio compass laboratories at Philadelphia Navy Yard, and at Germantown, Pa., and at the radio compass stations at Cape May, Cape Henlopen, and Bethany Beach. These comprised bearings taken on various transmitters (800-meter) within a range of 5 to 200 miles. A typical set of results for spark signals were reproduced in my article, "The Radio Compass"[7]. The deviations for spark signals ranged from 4 to 5 deg.; under the same conditions the arc signals varied by twice this amount. I have always thought that this difference was to be attributed to the homogeneity of the CW signals on the one hand, and to the fortuitous character of the spark as a radio-frequency time event, on the other. A simple calculation shows, moreover, that for the heights of the reflecting layer usually considered probable and at moderate distances (100 miles) the refracted signal may easily fall in between direct signals from a 500-cycle transmitter sparking twice per cycle. The change in musical quality accompanying this has often been observed. The studies of Bown, Martin, and Potter on isochronous fading with modulated CW signals are of interest in connection with this subject.

H. E. Hallborg:[8] I am very much interested in the Adcock system, particularly in view of its applicability to short-wave direction-finding. The satisfactory solution of the problem of direction-finding in the wave band of 50 to 200 meters is of particular importance to the air mobile service. It is my impression that the Adcock System should be particularly useful in this wave band.

Dr. Taylor has pointed out, in the previous discussion, that one of the limitations of the system is its relatively low pick-up, necessitating high amplification. Fortunately, this natural limitation obtaining at wavelengths of the order of 850 to 950 meters progressively diminishes as the wavelength of operation is shortened to the 50-to 200-meter band. Consequently the available antenan exposure progressively becomes a larger fraction of a wavelength. The pick-up effectiveness of the system at short wavelengths is thereby automatically improved.

The above is a superficial analysis of the possibilities of the system for short-wave direction-finding. I would like to hear a further discussion by either Dr. Hull or Dr. Taylor as to whether the accuracy of the system on wavelengths of say 100 meters might be expected to be as good as that shown by the system on longer wavelengths.

L. M. Hull: With regard further to the sensitivity of the Adcock receiver, the small, portable, rotating model, of which a picture is shown in the paper, was first designed by Mr. Barfield, I believe, with the idea of using it for taking bearings on broadcast wavelengths. It was provided with a double detection receiver which was as sensitive as could be conveniently fitted to it at the time, and the sensitivity of that particular receiver was found to be inadequate for the purpose. So making a virtue of necessity this particular unit was used in an investigation of lateral deviations at frequencies on the order of 7 or 8 megacycles.

I had the opportunity one afternoon of observing with a similar model the bearings on a German station which was transmitting at about 40 meters throughout the course of the afternoon. I had been told previously that the model had been perfectly compensated, so that there was no appreciable response to horizontal components, and consequently any deviation in the bearing would probably be attributed to true lateral deviation of the waves. In this particular

[7] Yearbook of Wireless Telegraphy and Telephony, London, 1921.
[8] Radio Corporation of America, New York, N. Y.

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case I observed a continuous deviation of the bearings, varying by the minute, through a maximum arc on the order of 7 or 8 degrees on this 40-meter transmission from a station at a distance of the order of 400 miles.

Of course, that question of sensitivity is a very important one, but in view of the fact that the technique of receiver design has advanced so by leaps and bounds in the last few years in this country, I believe that it is perfectly feasible to design and use special receivers even with portable Adcock direction-finders of this type, at the longer or intermediate wavelengths.

With regard to the reliability of the receiver, I don't exactly know what you mean. It is, of course, very difficult, particularly at the high-frequency ends of the spectrum, to say definitely that you have perfect compensation of the horizontal limbs. In the case of an Adcock receiver designed for reception at 400 meters or at lower frequencies, the observation of bearings, which are constant to the extent indicated on the curves shown in the paper, would immediately present evidence that the receiver was properly balanced. But so far as I know, it is in general impossible to obtain such constancy of bearings with the Adcock receiver on short-wave stations. It is simply necessary by independent measurements to assure yourself that the horizontal limbs of the collector have been balanced as perfectly as possible, and then to attribute what deviations you may observe to lateral deviations of the wave, which may of course possibly be refracting effects in the ground waves in cases where the deflected wave is not important, or which may be actually oblique deflections of the downcoming waves at considerable distance.

Stuart Ballantine: Did they balance that system with respect to ground currents?

L. M. Hull: In the model which I saw operating, the effects of ground currents were minimized by setting it as high off the ground as possible.

A. Hoyt Taylor: The theory of the system requires that the waves reflected up from the ground shall not introduce errors.

I might say that one way of carrying out your compensation on sufficiently high frequencies, that is, frequencies above 6000 kc, would be to set up a transmitter a few miles away so that you could get a ground wave of some little strength but have your sky wave skip over it. Compensate it then for a true vertically polarised ground wave. You could probably check your compensation pretty well. There is no doubt but that the compensation on the higher frequencies is extraordinarily difficult to keep in order.

As to the question asked by Mr. Hallborg concerning aeroplane bearings, if he will ask me that question a month later, I may be able to give him some information.

S. W. Dean[9]: Mr. Chairman, Mr. Smith-Rose and his associates of the Radio Research Board have done a great deal of very fundamental work on problems of the nature of those discussed in the paper, and also on those which involve the propagation of radio waves from a different point of view; that is, from the point of view of variations of signal strength, rather than of bearing. In this connection, Hollingsworth has shown that as you proceed from a long-wave transmitting station in a given direction, the signal strength passes through a series of maxima and minima of decreasing amplitude. This was observed at distances up to a few hundred miles.

Some of these results seem to be somewhat in disagreement with results ob-

[9] American Telephone and Telegraph Co., New York, N. Y.

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tained in this country. This disagreement was mentioned by Dr. Austin in his "Report of the Chairman of the Commission on Radio Wave Propagation, International Union of Scientific Radio Telegraphy."[10]

I should like to mention a few examples of the difference between results in England and in America, which have come to my personal attention. In one case a portable field strength measuring set was taken on a truck from the vicinity of Long Island up to the northern part of Maine, and observations were made at fairly frequent intervals on transmission from Rocky Point, Long Island using a frequency of 60 kc. The decrease in signal strength as the distance was increased followed a smooth curve closely approximated by the usual type of transmission formula, with no trace of maxima and minima. On the contrary the results obtained in England under similar conditions showed maxima and minima.

One suggestion I would like to make as a possible explanation of this is the difference in the conductivity of the ground in this country and in England. We have quite a number of evidences of that difference. One was mentioned in the paper which Dr. Bailey recently presented here on "The Receiving System for Long-Wave Transatlantic Radio Telephony."[11] This is that wave-antennas constructed in the United States have considerably greater output than those built in England, due to the greater wave tilt in this country. This was attributed to the difference in ground conductivity.

Another evidence (of minor nature) is that in some of the work which we have done in America on long-wave direction-finding, we found considerable errors in the measurement of both direction and field strength caused by underground wires and pipes near the receiving antenna. These errors in direction amounted to 5 or 6 deg. on the European stations, while the errors in field strength amounted to practically 2 to 1 in some cases. While in England I had occasion to look for such errors in a similar set-up of a field strength measuring set with loop antenna, and although there were fully as many buried wires, cables, and pipes, in this case the errors were practically negligible both in direction and in field strength. The apparatus was tested for such errors by comparing the results obtained with fixed measuring sets at stations where there were wires, cables, and pipes under the ground, with measurements made with portable sets in the open country which were not subject to such conditions. It occurs to me that the reason for this difference in results in the two countries may also be due to the difference in conductivity of the ground; that is, the ground being so much more conducting in England shields the buried pipes and cables much better than does the poorly conducting soil in this country. I cannot offer an exact explanation of why that difference in ground conductivity should cause the Radio Research Board in England to observe maxima and minima of signal strength as they progress away from a transmitting station, but the conductivity seems to be the only factor which is definitely known to be different in the two countries.

One or two other experiences which I had while working in co-operation with the engineers of the British General Post Office may shed some light on this question.

At the Post Office Radio Station at Cupar, Scotland, we observed daily for a period of about three months the signal from Rugby, England on 16 kc, at a distance of about 400 miles. Apparently we were located at a point where

[10] Proc. I. R. E., 16, 348; March, 1928.
[11] A. Bailey, S. W. Dean, and W. T. Wintringham, Proc. I. R. E., 16, 1645; December, 1928.

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(in the summer daytime) one of these minima existed. The calculated field strength of the station was about 8,000 μv per meter, as I remember it, but the daytime values were very irregular and averaged about 400 μv per meter, the bearings being very indefinite and sometimes more nearly at right angles to the true direction than in the true direction. At sunset, however, the field strength began to rise rapidly, and shortly after sunset reached its calculated value and sometimes exceeded it. We had there very concrete evidence of the existence of a standing wave pattern on the surface of the earth, as has been described by Hollingsworth of the Radio Research Board.

Another, and even more striking example of such a condition, occurred one night when we were observing the same transmitting station, Rugby, but this time on 60 kc, as received on two wave antennas approximately 2 miles apart. During the course of the evening the relative strength of the signals on these two antennas varied greatly. At one time, to the great surprise of everybody present, the signal practically disappeared on one of the antennas while being received at considerable strength on the other antenna 2 miles away. I would hesitate to make such a statement except for the fact that there were two other observers present at the time.

I mention these things to emphasize that there is a very real difference between radio transmission phenomena in this country and in England. While interference effects and standing wave phenomena have often been observed in this country on broadcasting frequencies, such effects have not been observed at frequencies below 100 kc, to my knowledge, to as great an extent as has been reported by the English observers.

William C. Bohn:[12] I should like to ask if you have ever experienced an improvement in the minimum obtained on a loop when the vertical axis of the loop was tilted.

A. Hoyt Taylor: That can be done under certain conditions, but it is not a general cure for the situation.

L. M. Hull: With regard to the establishing of a standing wave pattern between the earth and the reflecting layer, it might be worth mentioning that such a pattern is made use of in one of the standard methods of determining the height of the layer by Prof. Appleton. One of his methods consists of making observations on a vertical antenna at a receiving station during "night errors" and observing the occurrence of maxima and minima as the frequency of the transmitter is continuously varied.

George R. Putnam[13] (by letter): This paper gives a summary of the interesting investigations carried on in England, during recent years, by Dr. Smith-Rose, and of other available information, in the field of radio direction-finding.

The subject is of especial interest in the United States, where there has been the most extensive development of a radio beacon system; the Lighthouse Service now has in commission 61 of these signals with 14 under construction. Since the first successful signals were established in 1921 near New York, this method of navigation has come into wide use; with the radio compass (or radio direction-finder) on shipboard, it successfully meets a most urgent need of the navigator, giving him the means of taking accurate bearings on invisible signals at great distances. There was never doubt of its universal use in marine navigation, so soon as some practical difficulties were removed, and its possibilities became known.

[12] American Telephone and Telegraph Company, New York, N. Y.
[13] Bureau of Lighthouses, Washington, D. C.

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Dr. Smith-Rose describes and discusses a system of navigation by bearings from a "rotating beacon." He compares its advantages with the above-mentioned radio beacon and radio compass system. But it is not a comparable system, and does not fill the same purposes, as the following parallel comparison shows:

Radio compass located on shipboard with radio beacons at lighthouses and on lightships.	Radio on shipboard, with bearings from a "rotating beacon" on shore.
1. A universal system; bearings available on any radio signal from shore or ship, throughout the world.	A limited system, bearings may be obtained only from these particular land stations.
2. Radio compass is a general navigational instrument, which the navigator can readily use himself, and the possibilities and reliability of which he can become accustomed to.	Navigator is wholly dependent on a system operated on shore, beyond his control; each station may be affected by peculiarities of personnel and location.
3. Of the utmost value in aiding ships in distress (for example, it made possible rescue of crew of *FLORIDA*, Jan. 23, 1929).	Not available for rescue purposes.
4. Of value to vessels approaching each other, in avoiding collision; already thus being used.	Cannot be used between ships.
5. Radio beacon may be placed on offlying lightships (and these are usually the most valuable stations).	"Rotating beacon" is not workable excepting on land; cannot be placed on a ship.
6. Accuracy sufficient for uses of navigation; with proper precautions and use, the reliability of the radio compass on shipboard is now superior to that on shore.	Accuracy is not greater.
7. Radio beacons can readily be placed at any lighthouse, or any lightship.	"Rotating beacon" can be located only on land, or on a fixed foundation.
8. Cost of installation of a radio beacon is somewhat less than that of a good sound-producing fog signal, while it effectively covers an area 200 times as large. Operation adds little to the cost of a lighthouse or lightship.	Cost not given, but evidently not less than for a radio beacon, and probably more.
9. Cost of radio compass on a vessel is not great in proportion to the universal service given by it, and is becoming less. There is no doubt but that inexpensive radio compasses will be available for small craft, and will be valuable even if less accurate.	The additional cost is only small, for a vessel equipped with radio.
10. The radio compass on shipboard is now indispensable on all properly equipped vessels of any size.	The "rotating beacon" would provide simply an additional check for vessels which must carry a radio compass.
11. This system is already established and in wide use.	No "rotating beacon" is in commission.

Some of the conclusions reached by Dr. Smith-Rose are based on practice different from ours. In this country the radio compass, from the first, has been installed on the bridge or in the pilot house of a vessel, often so located that the bearing may be read directly on the magnetic compass or a gyro-repeater, thus quite eliminating the principal source of error which he describes at length,

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resulting from the bearing being taken by the radio operator in the radio room. Here the radio bearings are taken directly by the navigator or under his supervision; besides other obvious advantages, the accuracy and reliability of radio bearings taken on shipboard are now believed to be superior to those taken at a shore station by personnel who are less expert in regard to navigation, and who have not the responsibility for, or the means of judging of their correctness.

The radio beacon can always be placed at an existing lighthouse or lightship, for these are the points of strategic importance to navigation which call for radio beacons.

It is evident that with the present state of the use of radio in navigation, ships must be equipped with a general means of obtaining radio bearings from the ship; there is only one general system available for this purpose, and so far as present knowledge goes none other appears to be possible. There can be no economy in any other system as it will not meet the need, and will not obviate the necessity for the radio compass on shipboard.

The above comment bears on the part of this paper wherein Dr. Smith-Rose departs somewhat from his field of research, and touches on navigational applications and lighthouse service economics, perhaps without realizing that several thousand of the principal ships of all countries are now daily using the radio compass on shipboard with satisfaction and success, and that there are well over one hundred radio beacons in operation, maintained by lighthouse services of the maritime nations at lighthouses and on lightships, and that these signals are now depended upon by the navigators perhaps more implicitly than any other; they are undoubtedly the most important aids to navigation.

The research results given by Dr. Smith-Rose are of the greatest interest and importance, and prove the value of the work planned by the Radio Research Board of England. Some of the results given in this paper are confirmed by the seven years'experience in this country in operating a radio beacon system, and by the reports received from vessels; as to other conclusions there is some divergence. As he states, the so-called night effect has not been found a serious hindrance in the use of radio bearings in navigation, under the conditions as applied here; the uncertainties on this account are not systematic, and increased accuracy can readily be obtained by repeated bearings.

The type of radio wave transmission, and the fog or other weather conditions, have not been found to have any influence on the direction of a radio bearing.

Experience here has shown no cases of error due to bearings crossing the shore line, or running parallel to the coast, and this has been confirmed by a considerable number of bearings taken from vessels on the Great Lakes, over land and water. The so-called land-effect is considered to be negligible in the radio bearing practice used here for navigation, and there appears to be no necessity for warnings as to "arcs of good bearings." Also in the system here developed of placing the principal radio beacons on lightships, or outstanding points on the coast, there is little occasion to use radio bearings which pass over the land.

The accuracy of 1 deg. ascribed to land direction-finding stations applies in our experience to the radio bearings taken from ships under good conditions.

I was much interested a coulpe of years ago in observing the experimental work which Dr. Smith-Rose was kind enough to show me. The "rotating beacon" may very likely have valuable applications, either for special localities, or special navigational needs, but it appears important to keep clearly in mind the

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requirements of radio bearings for general marine navigation, which can be met only by a truly general system.

J. C. Schelleng[14] (by letter): In the paper the author mentions that reservations are necessary in the application of the reciprocal theorem to actual radio transmission. In his generalization of the reciprocal theorem, Carson[15] pointed out that it appears necessary that the currents in the system be linear functions of the potential gradients involved.

These conditions are not strictly satisfied in the case of transmission through media such as the ionized upper atmosphere for two reasons.

> (1) Motion of the ions across the magnetic field of the wave itself produces a small additional motion in the direction of propagation. This motion is such a function of the wave amplitude that it can be neglected for the small amplitudes used in practice. With this reservation the reciprocal theorem is probably valid in such cases.
>
> (2) A real failure of reciprocity occurs when a constant magnetic field, such as that of the earth, is considered. The lack of reciprocity in this case has been recognized by several writers. A simple example is the following. An ionized medium containing the points A and B has a magnetic field in the direction AB. Perpendicular to this line at A and B are two linear antennas, A is vertical but B is rotated 45 deg. from the vertical. The distance AB is chosen so that when A is energized, the plane of polarization of the resulting wave, in passing from A to B also rotates 45 deg., resulting in a maximum signal in B. In this case the wave has been travelling in the direction of the magnetic field. When, however, B is the transmitter and A the receiver, the plane of polarization, instead of rotating back to a position parallel to A, rotates an additional 45 deg. in the same direction as before and at A is perpendicular to the antenna. The current in A is therefore zero. The reciprocal relation therefore fails.

For the phenomena to have been reversible would have required a reversal of the magnetic field at the same time as the change in direction of propagation. While proof is lacking, it seems not unlikely that this relation holds in more general cases than the special one given; that is, that in general reversibility is obtained in transmission through such media providing that all externally applied magnetic fields are reversed with the direction of propagation.

That such considerations have a great deal to do with directional errors is, of course, well appreciated by Mr. Smith-Rose. It may be of interest to consider the question in some detail. Neglecting errors due to departure from the great circle path, though such departures certainly exist, at any rate for short waves, deviations in apparent bearing are due to the existence of a horizontal component in the downcoming electric field, which in turn is due to the earth's magnetic field. If the direction of this magnetic field could be reversed, the direction of the disturbing electric component would be reversed and with it the sign of the directional error.

In Fig. 1, A and B are two geographical locations, viewed as on a map. The arrow on the line AB indicates the direction of propagation. The arrow D gives the apparent direction indicated by a loop receiver or transmitter at the point shown. V indicates the use of a vertical transmitting or receiving aerial. H is the magnetic field, assumed horizontal. The shape of the path from A to B is assumed symmetrical with respect to the mid-point.

Fig. 2 indicates that if the magnetic field could be reversed, the directional error would also be reversed.

[14] Bell Telephone Laboratories, New York City.
[15] *Bell Sys. Tech. Jour.*, July, 1924

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Fig. 3 is obtained from Fig. 2 by rotating the system of Fig. 2 by 180 deg. about a vertical axis. Such rotation assumes that AB is small enough so that conditions along the path are uniform in regard to ionization, etc. Comparison of Figs. 1 and 3 indicates that under otherwise identical conditions a loop receiver at A indicates a directional error the sign of which is opposite to that observed in the same way at B.

Fig. 4 is obtained from Fig. 1 by assuming both the magnetic field and the direction of propagation to be reversed. Fig. 5 is obtained from Fig. 4 by rotating the entire system as before.

Comparing Fig. 1 and Fig. 5, the apparent directions in the two systems (loop receiver and loop transmitter) are seen to be the same as long as the wave always moves from A to B.

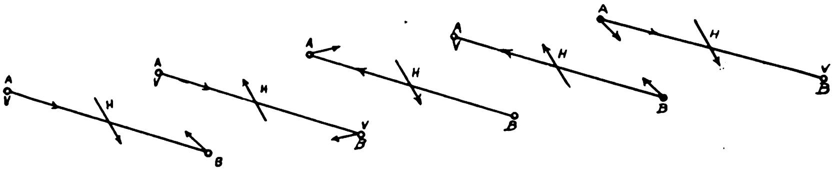

Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5

Comparing Fig. 3 and Fig. 5 the errors are opposite in sign if the directions of propagation are opposite in the two systems. This case applies to the statement at the end of Sec. 4 of the paper. It would therefore appear at least for a horizontal magnetic field, that *regardless of the disposition of the apparatus the errors are the same as long as the directions of propagation are the same.* It should be repeated, however, that this assumes uniform conditions along the path. The statement also requires some modification if the path is not short compared to the radius of the earth.

If, as seems likely, the present assumptions are correct in general, and if readings in the two directions could be taken closely enough together, equal errors of opposite sign would be obtained merely by reversing the direction of propagation through the same terminal apparatus. An average of the apparent directions in the two cases would therefore be free of error produced by rotation of the plane of polarization.

When the directional errors fluctuate and are positive as often as negative, either the difference in the lengths of the paths of the overhead and the ground wave must vary at random between limits of a wavelength or more, or else the plane of polarization of the overhead wave must vary in general through a range of at least one revolution. Fig. 14 of the paper would appear to represent such conditions. Incidentally this experiment did not afford a test of the instantaneous reversibility of the system, since conditions were fluctuating too rapidly during the ten-minute intervals which were used. It appears from the above considerations that the system is not reversible. Reversibility of the average bearings seems to have been obtained in this experiment and may indeed represent the usual conditions. A state of affairs can be imagined, however, in which the atmospheric wave would be so steady that a more or less constant non-reciprocal atmospheric error would be introduced.

Incidentally this term "atmospheric error" may in some ways be preferable to "night error." It is non-committal as to the exact mechanism (rotation or actual deviation from the path), except that it is due to a wave returned by the upper atmosphere. It can be used without explanation when such effects occur in the daytime, as they do for short waves.

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Discussion on
RECENT DEVELOPMENTS IN SUPERHETERODYNE RECEIVERS*

(G. L. BEERS AND W. L. CARLSON)
(Communicated)

Frederick K. Vreeland†: This paper is of especial interest to me because the apparatus described employs a band selector, used as an interstage coupling in an amplifier, as set forth in my paper presented to the Institute January 9, 1928. In the present case the band selectors are employed in the intermediate-frequency amplifier, and they are of the form which employs a mutual inductive coupling between the selector elements, instead of the form that has a bridging inductance coil, which is usually preferable.

This raises a question of practical interest as to the relative merits of selectivity in the intermediate-frequency as against radio-frequency selection. In the apparatus described the radio-frequency selection is of the broad resonance type.

It is usually considered that intermediate-frequency selection is the more selective, since the absolute frequency difference between two waves to be selected is the same in either case, while the relative separation, expressed as a fraction of the frequency, is larger at the intermediate frequency, since this frequency is lower. The figure of merit of a selector is naturally a function of the relative separation, rather than the absolute frequency difference.

The curves given in the paper do not, however, fulfill this expectation, especially when it is realized that eight tuned circuits are employed. The overall frequency characteristic, Fig. 15, lacks the substantially rectangular form, with flat top and sharp cut-off, that characterizes band selection at its best, and the effect of this on the fidelity curve appears in Fig. 16, which shows the 5,000-cycle component reduced to 30 per cent of the normal and the 10,000-cycle component practically out.

It would seem that this result can be traced to two causes: first, the intermediate-frequency selectors, and secondly, the resonant radio-frequency circuits.

Referring to the frequency characteristic of the intermediate-frequency selector, Fig. 7, it will be noted that the curve has a rounded top and sloping sides, instead of the flat, or even hollow top and sharp cut-off of a good radio-frequency band selector. Two factors, and perhaps others, contribute to this result. First, the large *relative* width of the band increases the difficulty of design, a twenty-kc band having a relative width, in this case, of 11 per cent of the carrier frequency, which is 180 kc, as against 3.3 per cent with a 600-kc carrier or 1.33 per cent at 1500 kc, when radio-frequency selection is used. Secondly, a low-frequency circuit has a larger power factor than a high-frequency circuit, for a given amount of space and material. These two factors increase the difficulty of design of selective circuits at the lower frequencies employed in superheterodyne amplifiers. But this difficulty is not prohibitive. It is quite feasible to make an efficient intermediate-frequency selector with good band form, but it requires more material, more space, and more elaborate construction than the corresponding radio-frequency band selector.

A second cause of the rounded and sloping characteristic may be found in the radio-frequency circuits, which appear from the description to be not band

* Presented at New York meeting of the Institute, March 6, 1929. PROC. I. R. E. 17, 501; March, 1929.
† Vreeland Laboratories, 90 West St., New York, N. Y. Discussion received April 9, 1929.

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selectors but broadly resonant circuits, as shown in Figs. 3 and 4. A marked improvement in both fidelity and selectivity could be secured by using more sharply resonant circuits and spacing them in the frequency scale, making a spaced band amplifier of the type described in the above-mentioned paper, or by the use of a single band selector in place of the two broadly tuned circuits. A band selector with a flat radio-frequency amplifier is a very effective combination.

There are also certain disadvantages in the inductively coupled form of band selector here used in the intermediate-frequency circuit. An important feature of the band selector with a bridging coil is that the band width may be varied at will by changing the inductance of the bridging coil. Thus a receiver may be converted, by a touch on a switch, from a full band selector, giving highest fidelity, to a narrow band or even a sharply peaked selector, when this is desired to cut through interference that overlaps the modulation band of the signal. This result is useful when extremely long distance reception is desired, since distant signals rarely have good quality because of ground noise and selective fading, and the band switch restores in a moment all the advantages of full band reception for nearer stations.

The "automatic volume control" is another feature that is analogous in certain respects to a system that has been developed and carefully studied in my laboratory for some time. I prefer the term "automatic governor" for our system because of the obvious analogy to the governor of a steam engine or turbine.

There are several features that we have found useful which differ from the arrangement shown in the paper. One of these is deriving the governing e.m.f. from the audio-frequency output, rather than from the radio carrier frequency. This has several advantages. First, it keeps the output level constant regardless of the degree of modulation, since the thing governed controls directly the governing function. Another feature that cooperates with this is designing the apparatus for quick response and slow recovery, so that changes in the dynamic of music or voice are rendered with their true relative strengths. This also removes the difficulty in tuning referred to in the paper, since the gain remains substantially constant for a sufficient time to tune accurately by ear without a separate indicator. The speed of recovery may be given any desired value, or changed at will. The slow recovery does not affect the speed of response to a suddenly applied signal, which is practically instantaneous. A large antenna suddenly switched on produces hardly a flicker in the output derived from a powerful signal.

A second avantage in operating on the audio-frequency output is that a much larger governing e.m.f. is available. The full e.m.f. applied to the loud speaker may be employed, or stepped up still higher by a transformer without the use of extra amplifiers. The scope of effective governing is thus enormously increased. An applied signal strength of 100,000μv or more is readily handled, as against 900μv, the largest value shown in Fig. 13.

This has the further advantage of permitting the governor to operate directly on the anode supply of the tubes, leaving the bias constant at its normal value and so avoiding the distortion that results from an excessive increase in the amplifier bias. This distortion due to bias control unfortunately occurs on the stronger signals, which are the ones most in demand for good tone quality. The most faithful reproduction occurs on the weaker signals, which are usually no good anyway. By governing the anode supply directly complete fidelity is

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obtained when the governor is operating to the limit on the most powerful signals, as well as on weaker ones, down to the limit of sensitivity of the receiver. Besides giving high and uniform fidelity, this method of governing makes a "sensitivity control" and a "resonance indicator" wholly unnecessary, thus greatly simplifying the manipulation. The operation is wholly automatic.

Operation of a receiver is still further simplified by another feature that I hope soon to be permitted to present to the Institute at length; that is, a remote control system for operating the station selector from a distance. This is naturally combined with the band selector and the automatic governor, and when so used permits the receiving set to be fully operated by a simple and inconspicuous control box, or by any one of several such boxes in different locations, using either a manual tuning adjustment or push buttons controlling individual stations. This reduces receiver operation to the minimum of simplicity and permits the receiver to be located in a closet, with only the loud speaker and control box in evidence, thus eliminating all cumbersome furniture. It is mentioned now as the logical sequel to the band receiver and the automatic governor.

G. L. Beers†: Coupled circuits have been used commercially for several years in superheterodyne receivers to improve their selectivity and fidelity characteristics. There is a decided advantage in having the intermediate-frequency circuits determine the selectivity of a superheterodyne receiver as by so doing the selectivity of the receiver can be made very uniform throughout the broadcast range. This of course is not the case with a tuned radio-frequency band selector, as in the best receivers of this type the band width varies three to one from one end of the broadcast range to the other. This rather serious limitation of tuned radio-frequency band selector receivers was explained in detail in the printed discussions of Dr. Vreeland's paper.

In a commercial receiver manufactured in large quantities like the one from which the data for the curve in Fig. 7 was taken, it is desirable to have a selectivity characteristic which is slightly rounded at the top. Such a characteristic is almost a necessity to enable the average broadcast listener to tune a receiver accurately. If the selectivity characteristic has a hollow top, the average user will tune the receiver to the peak on one side and sideband discrimination will be the result. From the standpoint of fidelity and selectivity, the slightly rounded top is unimportant. After the desired band width at 70 per cent peak amplitude has been decided upon, the relative merit of band selectors can be expressed by the ratios of their band width at 70 per cent peak amplitude to their band widths at 0.1 per cent peak amplitude. A brief comparison of this nature will soon demonstrate the superiority of the superheterodyne receiver over the tuned radio-frequency band selector receivers, which are on the market today. In this connection it is indeed unfortunate that Dr. Vreeland neglected to show overall selectivity curves for a tuned radio-frequency band selector receiver.

The tuned radio-frequency circuits in a superheterodyne receiver are used primarily to reduce undesired responses and as sufficient reduction in these responses was obtained by the use of the tuned circuits, it was unnecessary to resort to coupled circuits.

The statement that resonant circuits coupled by means of a bridging coil have a decided advantage over the inductively coupled type, in that the band

† Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Discussion received June 17, 1929.

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width can be varied at will by means of a switch, is incorrect. There are several simple ways of accomplishing this result with inductively coupled resonant circuits. Several experimental receivers in which such arrangements have been incorporated have been in use for several years. Here again the advantage is in favor of the selectivity in the intermediate-frequency circuits as any change in the band width of these circuits will cause a uniform effect in the selectivity of the receiver throughout the broadcast range. Varying the coupling in a broadcast receiver of the tuned radio-frequency band selector type will produce only a slight improvement in the band width at the high-frequency end of the broadcast range, since the losses in the individual circuits are too great to give a sharp characteristic.

The objections to an automatic volume control arrangement such as described by Dr. Vreeland are so numerous as to prohibit a discussion of all of them. The chief objections follow:

Dr. Vreeland states that the automatic volume control he has been using maintains a constant audio output level regardless of the degree of modulation of the incoming signal, and yet variations in the sound intensity of the music or speech which are produced by changes in the per cent modulation are rendered with their true relative strength. This combination of results hardly seems possible in view of the quick response and slow recovery claimed for the device.

Let us suppose that such an automatic volume control having a quick response and slow recovery, whose controlling e.m.f. is derived from the audio output, is in use in a radio receiving set. A program is being received from a station whose carrier is modulated 20 per cent, and the receiver is adjusted for the desired output. In accordance with the music the per cent modulation suddenly increases to 80 per cent. The audio output, however, does not change appreciably, but remains at practically the same level due to the quick response of the device. If the per cent modulation now returns to the former level of 20 per cent the audio output will decrease accordingly, since the volume control has a slow recovery and will, therefore, be much less than the output previously obtained with the same per cent modulation. If the per cent modulation remains constant for a sufficient length of time the audio output will gradually increase until it reaches the original level. It is evident that such a system cannot reproduce the variations in sound intensity so essential for the faithful reproduction of either speech or music.

When but one stage of audio amplification is used, sufficient radio-frequency voltage is readily obtained at the grid circuit of the detector to operate satisfactorily an automatic volume control. While not indicated in the curve shown in Fig. 13, the automatic volume control described in the paper will likewise control satisfactorily a field strength of 100,000μv per meter. The curves in the paper were plotted up to field strengths of only 900μv per meter to show in more detail the shape of the curve where the volume control starts to take effect.

The distortion encountered by the use of high negative biases on amplifier tubes in obtaining volume control is not eliminated by a volume control which varies the plate voltage instead of the bias, as a brief study of tube characteristic curves will show.

Dr. Vreeland's statement that the automatic volume control he has been using eliminates the necessity for a sensitivity control is misleading. There is actually more need for a sensitivity control with an automatic volume control of the type which he describes. Although the noise in tuning between stations will be

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reduced somewhat, it will still be objectionable and a sensitivity control will be very desirable. Also during a pause in a radio program, since there is no modulation, the sensitivity of the receiver will automatically be increased until either sufficient noise is received to work the control, or else the radio-frequency amplifiers or the detector will be overloaded. Either of these conditions is, of course, very undesirable.

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MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards, and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R113 Eckersley, T. An investigation of short waves. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 255–260; May, 1929.

(Abstract of an extensive paper discussing echoes and scattering effects, errors and their sources in direction finding, fading, magnetic storms, and the theory of the action of the Heaviside layer.)

R113 Quäck, E. and Mögel, H. Double and multiple signals with short waves. Proc. I. R. E., **17**, pp. 791–823; May, 1929.

(Results of oscillographic tests of round-the-world signals. Relations to magnetic effects and twilight zone.)

R113 Quäck, E. and Mögel, H. Short range echoes with short waves. Proc. I. R. E., **17**, pp. 824–829; May, 1929.

(Oscillograph records showing short range echoes and round-the-world signals simultaneously.)

R113.1 Parkinson, T. Some observations of short-period radio fading. Bureau of Standards Journal of Research, **2**, pp. 1057–1075; June, 1929.

(Causes of fading are investigated by means of graphic fading records made simultaneously with different types of receiving antennas. Evidence found of fading due to interference; to direction shifts; to rotation of plane of polarization, and to varying intensity of indirect rays; to multiple rays.)

R113.5 Mesny, R. Activie solaire et propagation. (Solar activity and propagation.) *L'Onde Electrique*, **8**, pp. 103–110; March, 1929.

(A summary of results of several investigators attempting to correlate variations in reception with periods of increased solar activity. Results of Espenschied, Anderson and Bailey, of Pickard, and Austin are considered.)

R113.5 Wymore, I. J. Relation of radio wave propagation to disturbances in terrestrial magnetism. Bureau of Standards Journal of Research, **2**, pp. 1201–1211; June, 1929.

(Study of radio reception on low frequencies showing that for daylight reception over distances of 4000 to 7100 km the signal intensity increases following the height of severe magnetic disturbances, while for distances of 250 to 459 km intensity increases before, is normal during, and increases after the maximum of a magnetic storm.)

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R125.1 Hell, R. Direktzeigendes funkentelegraphisches Peilverfahr. (A direct reading radio direction finder.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 138–145; April, 1929.

(Discusses a method of using two crossed receiving loops or one loop and a vertical antenna in connection with a switching arrangement and a current indicator for determining course. The indicator shows pilot continuously his position with respect to the course.)

R125.6 Chireix, H. French system of directional aerials for transmission on short waves. *Experimental Wiresless and Wireless Engr.* (London), **6**, pp. 235–244; May, 1929.

(Principles and construction of antennas for uni-directional horizontal beam transmission, using only one pair of feeders.)

R132 Jackson, W. The measurement of the voltage amplification factor of tetrodes. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 252–255; May, 1929.

(A bridge method for measuring the amplification factor and plate resistance (hence mutual conductance) of tetrodes, as affected by changes in battery voltages.)

R133 Hollmann, H. E. Zum Problem der Erzeugung kurzer elektrischer Wellen durch Bremsfelder. (Production of electric waves having a wavelength of the order of 13 to 18 centimeters.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 128–132; April, 1929.

(A thorough investigation into the production of 13- to 18-cm electric waves using a metal T.M.C. type tube. Also a comparison of results with those attained by Pierret and by Barkhausen and Kurz.)

R134 Terman, F. E. and Dysart, B. Detection characteristics of screen grid and space charge grid tubes. PROC. I. R. E., **17**, pp. 830–833; May, 1929.

(Measurements of the "voltage constant" of tetrodes and comparison of tetrodes with triode detectors.)

R145.3 Positive and negative mutual inductance (editorial). *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 233–234; May, 1929.

(Discussion of proper convention to be used in indicating sign of mutual inductance. It is shown desirable to call the mutual inductance positive if, having adopted a convention as to positive direction of currents, an increase of current in circuit 2 causes an e.m.f. in circuit 1 in the same direction as would be caused by an increase of current in circuit (1.)

R145.3 Bashenoff, V. I. The establishment of a general formula for the inductance of single turn circuits of any shape. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 245–251; May, 1929.

(It is shown that the ordinary formulas for single-turn circuits are special cases of the author's general formula. Experiments are made on large and small closed aerials, checking the accuracy of the general formula.)

R149 Shaw, A. E. Cold-cathode rectification. PROC. I. R. E., **17**, pp. 849–863; May, 1929.

(Investigation of discharge phenomena and asymmetric conductivity in gas-filled cold-cathode rectifiers.)

R170 Smith-Rose, R. L. Man-made static—high voltage overhead electrical transmission lines and radio interference. *Wireless Wld. and Radio Rev.*, **24**, pp. 476–480; May 8, 1929.

(A discussion of radio interference due to high-voltage transmission lines. Description of experiments conducted at the National Physical Laboratory by the author.)

R170 Allen, J. G. Radio interference. PROC. I. R. E., **17**, pp. 882–891; May, 1929.

(A consideration of the sources of interference and methods of detection and elimination.)

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R200. Radio Measurements and Standardization

R201.6 Soucy, C. I. and Bayly, B. deF. A direct reading frequency bridge for the audio range based on Hay's bridge circuit. Proc. I. R. E., **17**, pp. 834–840; May, 1929.

(A simple and accurate bridge in which the frequency is determined directly by the resistance introduced for balance.)

R261 Lubcke, H. R. Vacuum-tube voltmeter design. Proc. I. R. E., **17**, pp. 864–872; May, 1929.

(Equation for optimum design for a given input range and meter.)

R261 Rhodes, H. E. A simple two-tube vacuum-tube voltmeter. *Radio Broadcast*, **15**, pp. 107–108; June, 1929.

(An apparatus of improved design for audio-frequency work.)

R300. Radio Apparatus and Equipment

R330 Westman, H. P. Two recently announced tubes.—The UY-224 and the UX-245. *QST*, **13**, pp. 41–43; June, 1929.

(Data on screen-grid a.c. heater tube, UY-224, and the amplifier tube, UX-245.)

R341 Neue Glimmlichtgleichrichter. (A new glow discharge rectifier.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 145–148; April, 1929.

(A description of the "Anatron," a product of the firm of Dr. G. Seibt. Also a comparison of this type of rectifier with the audion type.)

R342.15 Podliasky, I. Sur les transformateurs intermediaires et la reproduction sans distortion. (On interstage transformers and reproduction without distortion.) *L'Onde Electrique*, **8**, pp. 111–118; March, 1929.

(Theory of resonance in transformers and its effect on frequency distortion. The effect of tube capacities is considered.)

R342.7 David, P. La qualite de la reception radiophonique. (The quality of radiotelephone reception.) 8th article of a series. *L'Onde Electrique*, **8**, pp. 119–129; March, 1929.

(Audio-frequency amplification. Circuit and speaker considerations involved in preserving quality in audio-frequency amplifiers. Discussion.)

R343 Lucas, P. S. Modern ideas on the portable receiver. *Radio* (San Francisco), **11**, pp. 12–13; June, 1929.

(Complete directions for constructing a compact 4-tube screen-grid set with power detector.)

R344.8 Meissner, E. R. Logarithmic scale for beat frequency oscillator. Proc. I. R. E., **17**, pp. 879–881; May, 1929.

(Equation for shape of variable condenser plates for giving a logarithmic frequency scale.)

R386 Kuhelmann, C. A. Chart for design of band-pass filters. *Radio* (San Francisco), **11**, pp. 18–19; June, 1929.

(Design data.)

R390 Fisher, E. H. Voltage surges in audio-frequency apparatus. Proc. I. R. E., **17**, pp. 841–848; May, 1929.

(Measurements of amplitude and frequency of transient voltages produced in audio transformers by opening the plate circuit. Discussion of protective measures.)

R500. Applications of Radio

R526.1 Pratt, H. Field intensity characteristics of double modulation type of directive radio beacon. Proc. I. R. E., **17**, pp. 783–878; May, 1929.

(Equations and graphs showing space pattern obtained with this beacon.)

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R526.2 Bouck, Z. Making the air safe for traffic—The lighthouse of the air—The radio beacon. *Radio News*, **10**, pp. 1065–1068; June, 1929.

(Description of work on radio beacon developed by the Bureau of Standards.)

R526.2 Gloeckner, M. H. Der Bordpeilempfanger im Flugzeug. (The direction finder on the airplane.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 132–138; April, 1929.

(A conclusion of discussion of the direction finder as applied to aviation.)

R526.2 Kahn, L. Nouvelles cartes aeriennes pour l'emploi de la T. S. F. en navigation. (New aerial maps for the use of radiotelegraphy in navigation.) *L'Onde Electrique*, **8**, pp. 87–102; March, 1929.

(New kinds of maps which simplify radio position finding in aerial navigation.)

R800. Non-Radio Subjects

621.313.7 Hermanspann, P. Hochfrequenz-Gleichrichter-Anlage mit automatischer Konstanthaltung der Gleichspannung. (High frequency rectifier with automatic voltage control.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 121–127; April, 1929.

(At a frequency of 8000 cycles a transformer with core of so-called Hochfrequenzblick shows a marked superiority to the air core type. A method of controlling voltage and keeping it constant and independent of the load is shown.)

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Proceedings of the Institute of Radio Engineers
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Institute of Radio Engineers

Forthcoming Meetings

BUFFALO-NIAGARA SECTION
Buffalo, N. Y., September 17, 1929

CHICAGO SECTION
Chicago, Ill., September 20, 1929

CLEVELAND SECTION
Cleveland, Ohio, September 18, 1929

DETROIT SECTION
Detroit, Mich., September 19, 1929

EASTERN GREAT LAKES DISTRICT CONVENTION
Rochester, N. Y., November 18-19, 1929

LOS ANGELES SECTION
Los Angeles, Calif., September 16, 1929

NEW YORK MEETING
New York, N. Y., October 2, 1929

PHILADELPHIA SECTION
Philadelphia, Penna., October 3, 1929

PITTSBURGH SECTION
Pittsburgh, Penna., September 17, 1929

SAN FRANCISCO SECTION
San Francisco, Calif., September 18, 1929

TORONTO SECTION
Toronto, Canada, September 16, 1929

WASHINGTON SECTION
Washington, D. C., September 12, 1929

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 17 September, 1929 Number 9

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The Institute of Radio Engineers

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SUGGESTIONS FOR CONTRIBUTORS TO THE PROCEEDINGS

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Professor Appleton was awarded the 1929 Morris Liebmann Memorial Prize for his investigations in the field of wave propagation phenomena. He was appointed to membership on the Committee on Meetings and Papers of the Institute in 1929 and has been an Associate member of the Institute since 1926.

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INSTITUTE NEWS AND RADIO NOTES

Eastern Great Lakes District Convention

The tentative program for the Eastern Great Lakes District Convention, to be held in Rochester, N. Y., on November 18–19, 1929, is as follows:

Nov. 17—	4 P.M.–6 P.M.	—Registration
Nov. 18—	8:30 A.M.	—Registration
	10:00 A.M.	—Opening Session and Technical Talks
	12:00 M.	—Luncheon
	1:00 P.M.	—Inspection Trip
	8:00 P.M.	—Technical Session
Nov. 19—	9:00 A.M.	—Technical Session
	12:00 M.	—Luncheon
	1:00 P.M.	—Inspection Trip
	6:30 P.M.	—Banquet

The executive committee of the Convention is composed of the following members: Virgil M. Graham, chairman; L. Grant Hector, vice chairman; L. E. Hayslett, secretary; H. J. Klumb, treasurer.

The Convention is to be sponsored by the Buffalo-Niagara, Cleveland, Rochester, and Toronto sections. All members of the Institute are invited to take part in the two-day program which is being arranged.

Appointment of Assistant Secretary

The Board of Direction of the Institute of Radio Engineers at its June 5th meeting authorized the Secretary to secure the services of Harold P. Westman, of Hartford, Connecticut, as Assistant Secretary. Mr. Westman joined the office staff on July 15th. He will be actively associated with the several standardization projects which the Institute fosters, and will have charge of the general correspondence in the Institute office. He comes to the Institute from the American Radio Relay League of Hartford, Connecticut, where he has been employed as technical editor of the magazine *QST* for the past several years.

H. B. Richmond Elected President of R. M. A.

H. B. Richmond, treasurer of General Radio Company, has been elected president of the Radio Manufacturers' Association for 1929–1930. Mr. Richmond for a number of years has been prominent in

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the Radio Manufacturers' Association as chairman of its Engineering Division. In that capacity he is succeeded by Walter E. Holland, of the Philadelphia Storage Battery Company. R. H. Manson, of Stromberg-Carlson Manufacturing Company, is to be in charge of the standardization activities of the R. M. A.

All of these gentlemen are well known to Institute members. Each has taken an active part in the work of the Institute's Committee on Standardization.

Books Received

Under this heading it is proposed, from time to time, to publish in the PROCEEDINGS brief announcements of new books received at the Institute's editorial office. Such an announcement will be found in the present issue. More extended reviews of books will also be offered as heretofore, although of necessity their preparation entails some delay.

Associate Application Form

It has been decided that the advertising section of each issue of the PROCEEDINGS will contain a condensed application form for Associate membership in the Institute. This form is placed in the PROCEEDINGS for the benefit of members who desire to have eligible non-members enrolled in this grade of membership.

The attention of the membership is again called to the fact that the names of non-member business associates may be used as references for Associate membership in the Institute if the applicant does not personally know five Associates, Members, or Fellows.

U. S. Civil Service Examinations

The United States Civil Service Commission announces open competitive examinations for the positions of physicist, ($3,800 per year), associate physicist, ($3,200 per year), and assistant physicist ($2,600 per year). Vacancies in the Bureau of Standards and Bureau of Mines, Department of Commerce, under the National Advisory Committee for Aeronautics and in positions requiring similar qualifications in other branches of the service will be filled from these examinations.

Applicants will not be required to report for examination at any place, but will be rated on education and experience (70 per cent) and

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writing, such as publications, reports or theses which are to be filed by the applicant, (30 per cent).

Members of the Institute interested in any of these positions should communicate with the U. S. Civil Service Commission, Washington, D. C. requesting Form No. 2600 and stating the exact title of the examination desired, referring to announcement No. 180.

1928 Standardization Report

There are still available a few copies of the reprint of the 1928 Standardization Report which appeared in the 1929 Year Book. One copy of this reprint is available free of charge to each member of the Institute upon request to the Secretary. To non-members the price is one dollar each.

World Engineering Congress

F. B. Jewett, vice president of the American Telephone and Telegraph Company, and C. W. Latimer, of the Radio Corporation of America, New York City, have been appointed the official representatives of the Institute of Radio Engineers at the World Engineering Congress to be held in Tokio in October of 1929.

Mr. Latimer is to present the paper, "Technical Achievements in Broadcasting and Their Relation to National and International Solidarity" which has been prepared by a Symposium Committee of the Institute. This paper is to be published in the November, 1929, issue of the PROCEEDINGS.

Incorrect Addresses

On pages XXI and XXII of the advertising section of this issue will be found the names of one hundred and twelve members of the Institute whose correct addresses are not known. It will be appreciated if members of the Institute having any imformation concerning the present addresses of any of the persons listed will communicate with the Secretary of the Institute.

Proceedings Binders

For the past several years the Institute has made available at cost a binder for copies of the PROCEEDINGS. Several hundred of these have been distributed to the membership.

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These binders serve as a very convenient means of preserving current issues of the PROCEEDINGS, since each individual issue is held in place by a wire strap without damaging the copy.

The binders are available at one dollar and fifty cents each, postpaid, from the Secretary.

Institute Meetings

JUNE NEW YORK MEETING

It was erroneously announced in a previous issue of the PROCEEDINGS that J. O. McNally presented the paper, "A Study of the Output Power Obtained from Vacuum Tubes of Different Types," at the June 5th meeting of the Institute in New York City. This paper was presented by the co-author, H. A. Pidgeon, of Bell Telephone Laboratories.

CONNECTICUT VALLEY SECTION

A meeting of the Connecticut Valley section was held in the auditorium of the Hartford Electric Light Company, Hartford, Conn., on July 11th.

E. A. Laport, of the Westinghouse Electric and Manufacturing Company, presented a talk on "The Installation of Three Radio Telephone and Telegraph Stations in China." Twenty-six members of the Institute were present.

SEATTLE SECTION

On June 4th a meeting of the Seattle section was held jointly with the Seattle section of the American Institute of Electrical Engineers in Eagles Auditorium, Seattle. A. V. Eastman, chairman of the section, presided.

S. P. Grace, assistant vice president of the Bell Telephone Laboratories of New York, presented a lecture and demonstration. The operation of many of the modern electrical marvels pertaining to sound transmission, including the following, were explained: the artificial larynx in use, the mechanical lung in use, the electric brain functioning, the electric ear functioning, the record of a heart beat, the evolution of telephony, a victrola playing a picture, the law of gravitation defied, delayed speech, scrambled speech.

Due to the unusual interest in this program, the desire of a great many people to attend, and the limited seating capacity of the auditorium, admission was by ticket only. One hundred and sixty members of the two societies and their guests attended.

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Committee Work

Committee on Admissions

A meeting of the Committee on Admissions was held in the office of the Institute on July 10, 1929 at 9:30 A.M. The following members were present: R. A. Heising, chairman; H. F. Dart, Arthur Batcheller, and E. R. Shute.

The committee considered a number of recommendations of the Committee on Membership for transfer of members to the higher grades of membership in the Institute.

Standardization Committee

Dr. Taylor has appointed the following chairmen of the subcommittees of the Committee on Standardization: C. B. Jolliffe, vacuum tubes; Haraden Pratt, transmitters; E. T. Dickey, receivers; H. A. Frederick, electro-acoustic devices.

1930 Convention

President Taylor has appointed a small subcommittee to arrange the technical program for the 1930 Convention. The membership of this Committee is as follows: K. S. Van Dyke, chairman; W. Wilson, H. M. Turner, and V. G. Smith.

The first meeting of the Committee was held on July 24th in the office of the Institute. Preliminary plans for the technical program were drawn up. Tentatively, the Committee plans a symposium, a lecture of popular interest, and two sessions of individual papers. It is expected that between twelve and fourteen papers will be presented at these four sessions.

Personal Mention

Harry R. Lubcke has recently become assistant director of research with the Crocker Research Laboratory of San Francisco.

Leroy Moffett, Jr., a recent graduate of the University of Oklahoma, is now student engineer with the Southwestern Bell Telephone Company at Oklahoma City, Okla.

Ray E. Stauffer has become associated with the General Electric Company at Schenectady, N. Y. in the radio engineering department. Mr. Stauffer was formerly a student of the University of Iowa.

Arthur V. Baldwin is now associated with the Johnsburg (Pennsylvania) Radio Corporation as radio engineer. Mr. Baldwin was formerly assistant engineer at the Canadian Westinghouse Company, Ltd., Hamilton, Ontario.

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William H. Doherty, formerly research associate, Radio Laboratory of Bureau of Standards at Washington, D. C., has recently joined the staff of the Bell Telephone Laboratories at New York City as radio engineer.

W. S. Duttera, of Gettysburg College, has become associated with the General Electric Company at Schenectady in the Radio Development Department.

Edward J. Fielding, formerly movietone engineer, Major Laboratories at New York City, has become assistant engineer with the Madison Square Broadcasting Corporation in New York City.

Frederick A. Holborn, until recently radio engineer with Federal Brandes Corporation at Newark, N. J., has joined the Gold Seal Electric Company of Newark, N. J., as chief engineer.

Sidney G. Knight is now associated with Les Laboratories Standard at Paris, France, having formerly been with the International Standard Electric Corporation at London.

D. Blair Mirk, until recently in London, England, with the International Standard Electric Corporation as radio engineer, has joined Les Laboratories Standard at Paris.

Glen R. Ogg, formerly chief radio electrician on the USS *California*, is now officer in charge of the U.S. Naval Radio Station at Brownsville, Texas.

Henry Tanck is now on the engineering staff of the Federal Telegraph Company at Palo Alto, Cal.

David G. Wyles, until recently radio engineer with National Electric and Engineering Company, Ltd., of Wellington, New Zealand, has become technical manager of Philipps Lamps, at Melbourne, Australia.

L. C. F. Horle, for a number of years chief engineer of the Federal Telephone Manufacturing Company at Buffalo, N. Y., is now located in New York City where he is practicing consulting radio engineering in radio design and development, and patent matters at the Hudson Terminal Building. Since the organization of the Buffalo-Niagara section of the Institute, Mr. Horle has served as its chairman.

H. H. Friend, Physics Department, Lehigh University, is now located in the Research Department of the Radio Corporation of America, New York City.

F. T. Brewer has joined the engineering staff of the Bremer-Tully Manufacturing Co. of Chicago as radio engineer. Mr. Brewer is a recent graduate of the University of Illinois.

L. W. Howard, a graduate of the University of California in the class of 1929, has become associated with the Federal Telegraph Co., Palo Alto, California, in the Engineering Department.

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Ray A. Montford, formerly assistant operator at Station WDAF at Kansas City, Mo., is now associated with the Western Electric Co. at Kearney, N. J., as equipment engineer.

William W. Waltz, formerly with the Electric Storage Battery Co. of Philadelphia, is now employed as installation engineer at the Electrical Research Products, Inc., New York City.

Edward N. Dingley, Jr., until recently asociated with the Bureau of Engineering, Navy Dept., as radio engineer at Washington, has joined the engineering staff of the Mackay Radio and Telegraph Co. at New York City.

Paul A. Kober is now associated with the Claud Neon National Laboratories of Long Island City. Mr. Kober was formerly connected with the Daven Corporation of Newark, N. J., on television problems.

Theodore H. Mann, formerly factory manager of Theodore Mann and Co. at Bielefeld, Germany, is now employed as laboratory assistant in the Sound Department of William Fox Studios at Hollywood, Calif.

W. B. Moorehouse, until recently associated with Westinghouse Lamp Co. as radio development engineer, is now employed as research engineer with the Bell Telephone Laboratories, Inc., New York City.

Walter F. Lanterman has resigned from the radio engineering department of the General Electric Company at Schenectady to become development engineer of the Universal Wireless Communications with headquarters at Chicago.

John B. Hawkins has recently become resident manager at United Reproducers Corporation, St. Charles, Ill.

John F. Farrington has resigned from the telephone engineering staff of the Bell Telephone Laboratories at New York to become radio engineer with the International Communications Laboratories, Inc., New York City.

H. R. Butler, for some time employed in the radio engineering department of the General Electric Company, has joined the staff at Wired Radio, Inc., as radio engineer.

Carl E. Welcher, formerly manager of Station WKEN at Buffalo, is now installation engineer with Electrical Research Products, Inc., New York City.

Thomas S. McCaleb, for several years electrical engineer with the Liberian government at Monrovia, W. Africa, has recently become associated with the Pan-American Airways, Inc., in the capacity of assistant communication engineer of the Mexican Division.

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M. G. McCarroll has left the General Electric Company at Schenectady to become sound technician with Paramount News in New York City.

E. G. Ports, until recently research engineer with the Bell Telephone Laboratories, Inc., is now employed by International Communication Laboratories, Inc., at New York City as communication engineer.

G. Edwin Stewart resigned from the National Broadcasting Co. and has become chief recording engineer of Paramount Famous Lasky Corporation at New York City.

Paul M. Segal, for a number of years attorney in the District Attorney's Office, Denver, Colorado, has joined the staff of the Federal Radio Commission as assistant general counsel.

John L. Weston, for some time associated with the General Electric Co. at Schenectady in the radio engineering department, has recently joined the Engineering Staff of Wired Radio Inc., at Newark, N. J.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 9 *September, 1929*

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED

August 7, 1929

Transferred to the Member grade

Dist. of Columbia	Washington, c/o Federal Radio Commission	Segal, Paul M.
	Washington, 3314 Newark St.	Mirick, C. B.

Elected to the Member grade

California	San Francisco, Signal Office, Presidio of San Francisco	Winner, William Lane, Jr.
Dist. of Columbia	Washington, Dept. of Commerce, Radio Division	Barron, J. H., Jr.
Illinois	Alton, 1124 Washington St.	d'Adrian, A. L. Duval
	Chicago, 1400 Union Trust Bldg.	Caldwell, Louis G.
Massachusetts	Waban, 100 Devon Road	Replogle, Delbert E.
Montana	Bozeman, c/o Montana State College	West, Glenn Edwin
New Jersey	Boonton, Radio Frequency Laboratories, Inc.	Wilmotte, R. M.
	Maplewood, 26 Berkeley Road	Pidgeon, Howard A.
New York	New York City, USS *Bridge*, c/o Postmaster	Johnson, C. M.
	New York City, 711 Fifth Ave., Room 1223	McElrath, George
Pennsylvania	State College, 234 West Fairmont Ave.	Woodruff, Eugene C.
Canada	Toronto, Ont., Windsor Arms Apts., St. Thomas and Sultan Sts.	Schwarz, Bertram A.
England	Leeds, Yorks, 35 Reginald Terrace, Chapeltown	Harvey, Lionel
	Leeds, 6 Blenheim Terrace, Northeastern School of Wireless	Russell, M. W. G.
	Manchester, British Broadcasting Corp.	Bird, R. J.
	Norbury, SW, 119 Headcorn Road	Shaw, A. C.
Germany	Berlin, Fritschestrasse 41, I, Charlottenburg	Roder, Hans
Italy	Milan, Corso Italia, 13, c/o S.I.R.A.C.	Osiatinsky, L.
New Zealand	Christchurch, Canterbury University College, Elec. Dept.	McLellan, Roderick Arthur
	Wellington, G. P. O. Box 638	Thow, Keith H.
Scotland	Dundee, 1 Lochee Road	Lyne, R. H.
	Edinburgh, "Dunelm," 8 Cluny Drive	Beveridge, John A.
Spain	Cartagena, Calle de Ignacio Garcia No. 3	Ramirez Eduardo Garcia

Elected to the Associate grade

Alabama	Birmingham, 1315 Woodland Ave., W. E.	Giglio, James A.
Arkansas	Little Rock, c/o Marine Hotel, Room 850	Beem, Arthur W.
	North Little Rock, 1301 W. 9th St.	McDonald, A. H.
	Little Rock, 1311 Commer St.	Minor, Robert Lee
California	Glendale, 1341 5th St.	Bockoven, Lewis Murray
	Hollywood, 814 No. Vista St.	Schiefer, C. Vreeland
	Los Angeles, New City Hall, Room 317	Chapple, James M.
	Los Angeles, 2848 Westview St.	Gronoff, Harry
Colorado	Denver, 3839 Yates	McClimans, Abner E.
	Denver, 1536 South Acoma St.	Strelesky, H. J.
Dist. of Columbia	Washington, 4201 9th St., N. W.	Fugazzi, Frank J.
	Washington, 1722 19th St., Apt. 706	Hudiburg, Rea S.
	Washington, 917 North Carolina Ave., S. E.	Monar, Fred B.
	Washington, 5806 Colorado Ave.	Murray, Philip J.
	Washington, 3308 14th St., N. W.	Zinnecker, H. K.
Florida	Orlando, 30 E. Pine St.	Shreve, A. French
Illinois	Chicago, 6038 Calumet Ave.	Hellman, Milton E.
	Chicago, 4865 North Hermitage	Hukle, R. M.
	Chicago, 1541 East 65th St.	Johnson, E. O.
	Chicago, 4250 W. North Ave.	Lagasse, Albert
Indiana	Indianapolis, 2136 North De Quincey St.	Chapel, I. C.
Kentucky	Ashland, c/o General Office, American Rolling Mill Co.	Carr, Edward Mayes
	Newport, 43 16th Street Clifton	Preuss, Arthur C.
Louisiana	Slagle	Hayes, Fred D.
Massachusetts	Belmont, 33 Willow St.	Sykes, Roger Allen
	Chicopee Falls, 121 East St.	Winstead, Theodore Bernard
	Great Barrington, 24 Silver St.	Parrish, Robert R.
	Salem, 27 Chestnut St.	Poor, Walter E.
	Sommerville, 46 Francesca Ave.	Dillaby, Edwin F.
	Springfield, 1283 Carew St.	Morehouse, Dayton J.
	Walton, 42 Brookfield Road	Clark, R. W. 3rd

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Michigan	Detroit, 10401 Jefferson Ave., E.	Harding, Lawrence Merle
	Detroit, 324 Hendrie Ave.	Schaefer, Richard J.
	East Lansing, Hermian House	Moore, Harold A.
	Jackson, Sparks-Withington Co.	Obright, C. Alvin
	Jackson, Sparks-Withington Co.	Strait, Clarence L.
	Kalamazoo, 216 Rose Place	Goldsmith, O. Brude
	Marshall, 301 N. Liberty St.	Faulkner, Douglas
	Ypsilanti, 406 Florence St.	Augustus, Lee M.
Minnesota	Minneapolis, 4912 41st Ave., S.	Roth, Harold B.
	St. Paul KSTP, St. Paul Hotel	Mills, H. Lawrence
Missouri	Independence, 109 Bowen St.	Beck, Ray
	Kansas City, 4707 Grand Ave.	Fouts, Avery L.
	Kansas City, 2904 Forest Ave.	Gundy, Clarence Van
	Kansas City, Federal Building, Room 231	McDonell, William J.
	Kansas City, 4211 Wabash Ave.	Swett, J. P.
New Jersey	Cliffwood, Bell Telephone Labs.	Crawford, Arthur B.
	Fort Monmouth	Hoppough, Clay I.
	Lawrenceville, A. T. and T. Co. Radio Station	Gilman, George William
	Long Branch, 165 Garfield Ave.	Herson, Jacob S.
	Roselle Park, 216 Filbert St.	Robinson, James W.
	Rutherford, 1 Erie Ave.	Wattson, Harry B.
New York	Brooklyn, 521 Monroe St.	Grainger, Maurice J.
	Brooklyn, 269 Fifteenth St.	Levine, Harry
	Brooklyn, 330 Bambridge St.	Perrin, Arthur G.
	Candor	Williams, Warren R.
	Elmira, P. O. Box 402	Downing, Richard E.
	Jackson Heights, L. I., 78 84th St.	Stotler, Albert
	Long Island City, 50–65 40th St.	Asch, Marcus
	New York City, 618 W. 136th St.	Carazo, Louis
	New York City, c/o Lexington Hardware and Radio Co., 1633 Lexington Ave.	Kaplan, Benjamin G.
	New York City, 583 Riverside Drive	Knight, J. B., Jr.
	New York City, 24 Walker St., Room 203	Nichols, Eldon
	New York City, 3063 Godwin Terrace	Rosenfield, Melville J.
	New York City, Radiomarine Corp. of Amer., 326 Broadway	Venner, E. G.
	Port Jefferson, 238 E. Broadway	Carter, Philip Staats
	Rochester, 200 Central Trust Bldg.	Burns, Robert G.
	Schenectady, 2334 Turner Ave.	Anson, C. T.
	Syracuse, 230 Roxford Road	Martin, George L.
Ohio	Canton, 137 Columbus Ave., N. W.	Faulstich, C. J.
	Cincinnati, 3120 Montana Ave.	Felix, Clarence George
	Cincinnati, Crosley Radio Corp.	Hunter, Theodore A.
	Cleveland, 2309 Roanoke Ave.	Burkhardt, Karl R.
	Cleveland, Research Labs., National Carbon Co.	Filgate, John T.
	Cleveland, 5800 Broadway	Martin, Frank J.
	Columbus, 2205 Summit St.	Stringfellow, William
	Springfield, 2103 Elmwood Ave.	Downey, William C.
	Springfield, 556 S. Limestone St.	Stolzenbach, R. W.
	Wooster, 408 W. Grant St.	Specht, Miles
Oregon	Portland, 901 E. Yamhill	Neubauer, Edwin William
Pennsylvania	Bethlehem, 520 W. Broad St.	Hottel, H. W.
	Bradford, 21 Thompson Ave.	Gimera, George
	Harrisburg, 401 Wiconisco St.	Heckman, J. W.
	Harrisburg, 1722 Boas St.	Poorman, Arthur E.
	Lansdale, 122 E. 5th St.	Schieber, Leonard B.
	Oil City, Box 514	Paca, William S.
	Philadelphia, 2924 Poplar St.	Greathead, Arthur W.
	Philadelphia, Moore School of Elec. Engr., U. of P.	Jen, C. K.
	Philadelphia, 6814 N. 16th St.	Lowe, Carr E.
	Pittsburgh, 1216 Chelton Ave.	Ostermeier, C. H.
	Sharon Hill, 32 Bonsall Ave.	Travis, Irven A.
	Swissvale, 7442 Washington St.	Stanton, J. S.
South Carolina	Columbia, c/o Perry-Mann Electric Co.	Buggel, William Edward Rose
Tennessee	Memphis, 505 South Main St.	Randolph, George T.
Texas	Houston, 1620 Main St.	Carter, William H., Jr.
	San Angelo, 16 South Milton St.	Jones, Frank M.
Australia	Strathfield, "Glenroy," 19 Concord Road	McIntyre, Daniel G.
Canada	Halifax, N. S., 69 Dublin St.	Crowell, A. M.
	Montreal, Que., c/o Northern Electric Co., Ltd.	Catton, W. R.
	Montreal, Que., Northern Electric Co., 637 Craig St. W.	Comach, Stanley I.
	Toronto 8, Ont., 34 Belhaven Road	Kitchen, C. P.
	Toronto 4, Ont., 7 Delaware Ave.	Nichols, W. A.
	Victoria, B. C. 1518 Cook St.	Murdoch, G.
	Weston, Ont.	Hollinsworth, V. E.
England	London SW1, 52 Eaton Terrace, Westminster	Troutbeck, Wilfrid H.
	Surrey, Sutton, "Gateside," Sutton Common Road	Howard, C. G.
	Wigan, Lancs., 4 Springfield St.	Evans, Alfred
India	Bombay, Indian Radio Telegraph Office	Enon, Ernest R.
Philippine Islands	Manila, 306 San Antonio Paco	Aglugub, Zacarias G.
South Africa	Johannesburg, P. O. Box 6461	Archer, C.

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South Rhodesia	Salisbury, P. O. Box 34, c/o Messrs. Hubert Davies & Co., Ltd.	Morison, Bruce

Elected to the Junior grade

Illinois	North Chicago, 1510 Sheridan Road	Taylor, H. S.
Kansas	Lawrence, 1024 Alabama St.	Wheeler, Frederick
Minnesota	Northfield	Griffith, Paul E.
Missouri	St. Louis, 2615 St. Vincent Ave.	Duffy, Charles A.
New York	Brooklyn, 825 DeKalb Ave.	Dlugatch, Irwin
	Yonkers, 448 North Broadway	Seitz, Frank A., Jr.
Washington	Vancouver, 1210 Harney St.	Ryan, Lloyd F.

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APPLICATIONS FOR MEMBERSHIP

Applications for election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to election of any of these applicants should communicate with the Secretary on or before September 30th. These applicants will be elected by the Board of Direction at its October 2nd meeting.

For Transfer to the Member grade

California	Palo Alto, Federal Telegraph Company	Suydam, Clinton H.
Illinois	Chicago, 5746 Drexel Blvd.	Deeley, Paul McK.
	Chicago, 2022 The Engineering Bldg.	Hayes, H. D.
	Chicago, 6222 Woodlawn Ave.	Keselton, Chas. C.
Massachusetts	Tufts College	Kenrick, Gleason W.
New Jersey	Westfield, 519 Alden Ave.	Baukat, Henry W.
New York	Baldwin, L. I., 17 Brookwold Ave.	Hoernel, Paul C.

For Election to the Member grade

California	San Francisco, c/o E. T. Cunningham, 182 2nd St.	Butler, E. W.
	San Francisco, 274 Brannan St.	Langevin, Carl C.
New York	New York City, USS *Wyoming*, c/o Postmaster	Fielding, Charles F.
	New York City, 463 West St.	Frederick, Halsey A.
	New York City, c/o Postmaster (U. S. Naval Mission to Brazil)	Holden, Carl F.
England	Rugby, Bilton Road, "Ladbrooke" House	Kinman, Thos. H.

For Election to the Associate grade

California	Beverly Hills, Fox Film Co.	Larsen, C. W.
	Covina, 165 No. Covina Blvd.	Ross, M. F.
	Culver City, Hotel Washington	Wersen, David T.
	Huntington Park, 2464 Randolph St.	Kirby, Melvin D.
	Los Angeles, 1839 E. Vernon Ave.	Tami, Joseph, Jr.
	Oakland, 7515 Weld St.	Madison, C. E.
	Oakland, 5555 East Fourteenth St.	Parkhurst, Edgar L.
	Palo Alto, c/o Federal Telegraph Co.	Harrison, Charles I.
	San Diego, 4558 32nd St.	Farnum, Willis H.
	San Francisco, 242A Hartford St.	Arrigoni, Arthur
	Sawtelle, 1446 Saltair Ave.	Spiller, Cecil Charles
Connecticut	West Haven, 12 Ward Place	Phillips, Ed. I.
Dist. of Columbia	Washington, Hqtr's U. S. Marine Corps	Cole, G. C.
	Washington, Naval Research Laboratory	Hentschel, Ernest R.
	Washington, 4107 Ingomar St., N. W.	Norton, Kenneth A.
	Washington, 226 8th St., S. E.	Wilkie, Harry
Illinois	Chicago, 4111 Ravenswood Ave., E.	Beard, J. Gregson
	Chicago, 744 Addison St.	Gay, Paul F.
	Chicago, 5317 Argyle St.	Hansen, Harvey Bennett
	Chicago, 1532 So. Homan Ave.	Levin, Sam
	Chicago, 2005 Prairie Ave.	Lopes, John
	Chicago, 1865 Daily News Plaza	McClintock, W. S., Jr.
	Chicago, 39 N. La Salle St., Room 1117	Scharf, Joachim Barschach
	Chicago, 4536 Magnolia Ave.	Shultise, Q. M.
	Chicago, 3547 Pierce Ave.	Thorsen, Orville T.
	Chicago, 4003 N. Kildare Ave.	Weibler, Carleton T.
	Great Lakes, U. S. N. Radio Station	Clark, Thomas F.
	Naperville	Stoos, Jos. A.
	Oak Park, 701 S. Kenilworth Ave.	Weiser, Carl
	Streator, 210 W. Lincoln Ave.	Melody, Bernard J.
Indiana	Valparaiso, P. O. Box 292	Norris, Sam
Iowa	Onslow	Koon, Cecil L.
Louisiana	New Orleans, c/o Tropical Radio Tel. Co., 321 St. Charles St.	Nall, Vance
Maine	Portland, 67 Bradley St.	Ryall, Henry
Maryland	Baltimore, 1626 Warwick Ave.	Cohen, H. A.
Massachusetts	Dorchester, 65 Monadnock St.	Hardy, Carroll N.
	Mattapan, 55 Goodale Road	Parnes, Henry
	Southbridge, 53 Oliver St.	Yates, Wilfred
Michigan	Detroit, 11391 Marlowe Ave.	Geiger, Arthur H.
	Flint, 830 Paddington Ave.	Lutos, Clifford
	Jackson, 214 N. Pleasant St.	Fortier, Raymond C.
	Jackson, R. R. #1, Harding Road	Lee, Kenneth G.

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	L'Anse	Fridgen, Edward N.
Minnesota	Minneapolis, 3519 24th Ave., So.	Kelly, James, Jr.
Missouri	Jefferson City, Radio Station WOS	Sloan, Fergus M.
	Kansas City, 6500 Paseo	Rippeteau, Chas. Wm.
New Jersey	Ampere, P. O. Box 58	Walz, Richard F.
	Deal, P. O. Box 122	Goodall, William M.
	East Orange, 44 Clifford St.	Pickard, Richard W.
	Lawrenceville, Box 132	Schwartz, Lyle H.
	Nutley, 31 Burnett Place	Humphrey, Hartley C.
	West Collingswood, 425 Taylor Ave.	Pettit, Albert R.
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Part II

TECHNICAL PAPERS

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 9 *September, 1929*

STUDIES OF ECHO SIGNALS*

By
A. Hoyt Taylor and L. C. Young
(Naval Research Laboratory, Bellevue, Anacostia, D. C.)

Summary—*This paper is a continuation of work reported in the Proceedings of the Institute of Radio Engineers for May 1928 by the same authors. A more extended study of echo signals with particular reference to directional characteristics and to diurnal variations has been carried out. Attention has also been given to the question of the relations between the echo signal and the frequency. Distortions, probably due to echo signals, have been recorded on long distance transmission. The relation between the echo signal and effective height of the Kennelly-Heaviside layer has been discussed.*

ALTHOUGH this paper is not primarily concerned with around-the-world signals which are not truly echo signals, it is nevertheless a continuation of the studies of high-frequency radio wave propagation published previously,[1] and therefore it will be proper to mention at the outset that one of the predictions in regard to the nature of round-the-world signals has since the publication of the earlier paper been found to be correct. In discussing the above mentioned reference it was stated that South American stations had not so far shown round-the-world signals, but that they might possibly be expected to do so in the high-frequency bands during the equinoctial periods and only at those times. Since it has a bearing on the general correctness of the analysis of conditions producing round-the-world signals previously given, it is interesting for us to be able to state that since the earlier paper was written round-the-world signals have been recorded on 21,500 kc from Buenos Aires operating then under the call LP2. These round-the-world signals were repeatedly noticed during the equinoctial periods of fall and spring, but have been noted at no other times, thus substantially verifying the prediction made in the earlier paper. A typical record of such conditions is shown in Fig. 1. The top line on the figure is the timing line produced by a 200-cycle tuning fork. The next line shows overlapping signals and echoes so that the signal was unreadable. The next line is again the timing line followed by a record, reading from left to right, which shows the tail end of the signal followed by a round-the-world echo, whose timing difference corresponds to approximately 0.14 second for a trip around the world. The next line is again the timing line followed by a record,

* Dewey decimal classification: R113.6. Original manuscript received by the Institute, March 20, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D.C., May 15, 1929.

[1] Taylor and Young, Proc. I. R. E., 16, 561; May, 1928.

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reading from left to right, which shows the letter A with weak round-the-world signals of both the dot and dash. By measuring from the end of the round-the-world signal corresponding to the dash back to the end of the dash itself, we again find a timing interval corresponding to a trip around the world of 0.14 of a second. A similar measurement can be obtained by measuring from the beginning of the dot to the beginning of the round-the-world signal following the dot and which is overlapped by the dash. Round-the-world signals from southern stations are then, as previously predicted, only ordinarily to be found close to the equinoctial period and not by any means every day even at that time.

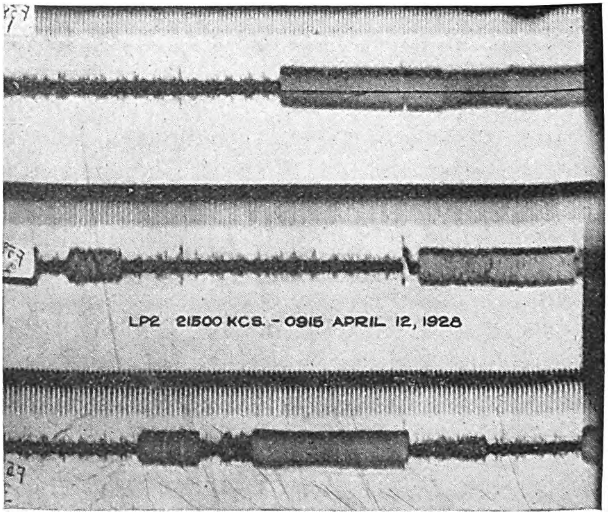

Fig. 1

It will be recalled that in the earlier paper simultaneous measurements were made on Rocky Point stations on the fundamental and the sub-harmonic of frequencies in the 18 mc band. It has been found that at certain hours of the day, depending somewhat on the season of the year, similar measurements can be made on South American stations excepting that in this case we are recording the transmitted signal and its harmonic instead of the sub-harmonic. It is, of course, understood that the sub-harmonic came from imperfectly shielded intermediate stages in the transmitter which were operating on one-half the frequency of the output and which coupled a small amount of energy in the antenna, which was nevertheless sufficient for recording.

In the case of the South American records shown in Fig. 2 on LP1,

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also at Buenos Aires, we have to do here with simultaneous transmissions, one of which is a real harmonic of the other. The upper line represents the transmission on 8500 kc and the lower one the harmonic on 17,000 kc. This record was taken at the hour 1745 on March 17, 1928. At this hour the Kennelly-Heaviside layer has not risen high enough to eliminate the upper frequency, but is high enough to permit good signals on both frequencies. It is assumed from the nature of the traffic that the station at this time was actually operating on 8500 kc. It is difficult to see, however, how the signals could have been read in this country on 8500 kc on account of prolongations of the signal due undoubtedly to short-time echoes, whereas the signal was extremely clear-cut and well defined on the harmonic frequency of 17,000 kc. It was thought at first that the tailing out or prolongation of the 8500 kc signals could be explained in the following way: If the layer were at an effective height of, say, 280 to 320 km, it would at this hour of the day permit both fairly low-angle and fairly high-angle rays to enter

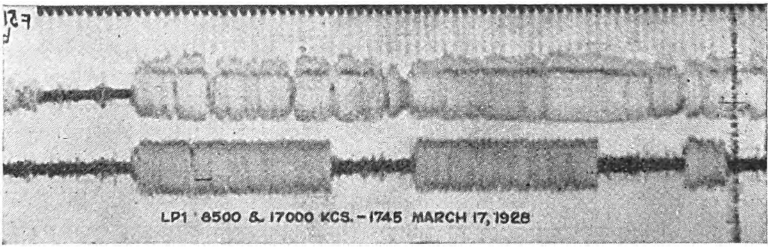

Fig. 2

into the reception at Washington. The low-angle rays would make only a few alternate reflections on the layer and earth on the way up from South America, whereas the high-angle rays would make a good many reflections and therefore would arrive later, thus prolonging the signal. That this effect actually does frequently occur we are well convinced. Indeed, it probably normally occurs except where the high-angle rays are prohibited either from too great a layer height or too great an absorption. But in this particular instance the overlap from 0.04 to 0.05 of a second is too great to permit this explanation to hold for it. Neither does the overlap seem to be of the proper magnitude to be accounted for at all by round-the-world signals. Indeed, there is no other indication, either in the pictures or by ear, of the existence of round-the-world signals at 8500 kc. This record is not only interesting because it cannot be readily explained, but is of practical importance as showing how this prolongation of the signal can practically limit the communication to very low speeds indeed. It should be clear from

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the record that the speed of communication at the time it was taken was not more than ordinary hand speed, and yet it was too fast for a clear and legible record to come through on 8500 kc on account of the above mentioned prolongations. On the other hand, the signals received at the same time on harmonic frequency could readily have been perfectly legible at high speeds as they were remarkably clear-cut.

Fig. 3 shows some records taken on Bogata, formerly called HJG, simultaneously on 13,700 and 27,400 kc. These records were taken in the daytime, and it will be noted that the 27,400 signal either arrives at the same time as the 13,700 signal or a little earlier. This probably indicates that the signal on the higher frequency is arriving by means of principally low-angle paths with less reflections than is the case on the lower frequency. This is in general accord with the idea that very high frequencies are restricted to relatively low angles except under conditions involving rather unusual electron distribution in the layer.

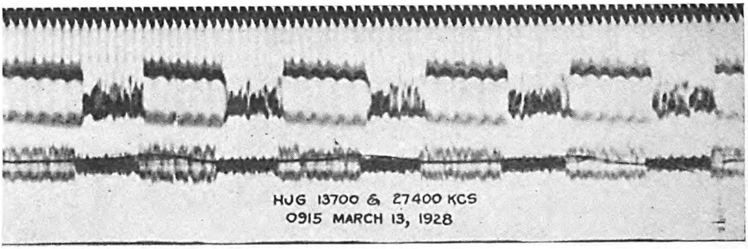

Fig. 3

The interval of lag on the front of the dots and dashes varies from 0 to 0.003 second; on the rear of the dots and dashes this interval varies from 0.00185 to 0.0035. These figures are based on a number of different photographs, only one of which is illustrated. This type of time lag or hang-over can probably be readily explained by the above explanation of different wave paths. These observations also show a sharper delineation of dots and dashes on the higher frequency, as they should if the explanation is adequate. It will be clear then that while the results shown in Fig. 3 just discussed are susceptible of explanation without reference to echo signals, the results in Fig. 2 must be interpreted as due to some kind of echo effect.

In order to carry out studies of short time echoes in such a way as to throw some light on the direction from which they come, it was decided to locate an observing center at some point out in the country where directive antenna structures could be effectively used and where interference would be at a minimum. The U. S. Coast and Geodetic

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Survey very kindly offered the Naval Research Laboratory the use of such a location at the Cheltenham Magnetic Observatory, which lies just off the Crane Highway at a point some eleven miles in an air line slightly south of east from the Naval Research Laboratory. It was found at this point that the ground wave which furnishes the timing basis for observations from our own transmitters could be received with sufficient strength to make an excellent record. There are absolutely no power lines, telephone wires, or other distorting and disturbing influences on this location, and we were therefore able to set up four long low, single-wire antennas to the four cardinal points of the compass, grounding the ends of them through resistances. A rather sensitive receiver was used for the work which had a stage of shield-grid radio-frequency amplification preceding the detector. A Westinghouse oscillograph was used for recording. The transmitters at the Naval Research Laboratory were provided with a contacting arrangement which permitted transmission of extremely brief dots so spaced that round-the-world signals would rarely be confused with short-time echoes.

Preliminary studies of the directivity of the four receiving wires were made by observing long distance stations and their general directive properties were found to be excellent. With very few exceptions western stations were invariably received more than three times stronger on the west wire than they were on the north and south wire, and were received scarcely at all on the east wire. The South American stations showed the same behavior with reference to the south wire. European stations, on the other hand, being from the northeast, came in almost equally well on the north and east wires, but very poorly on the south and west wires. There were two exceptions to this check on the directivity of the receiving wires. Occasionally European stations would come in phenomenally well at certain hours late in the evening on the south wire, but these were clearly exceptional cases for which we have no adequate explanation. Another exception was that our own station which should have sent its ground wave in with the greatest strength on the west wire was in fact received much better on the north wire. Since, however, the frequencies used were rather high and the country in between was extremely rough and hilly, it is quite easy to see that violent distortions of the ground wave pattern could readily account for this result, and the general action on long distance signals gave us reason to expect that the directional results obtained on echo signals would be sufficiently reliable. In our earlier paper we made the suggestion that the short time echoes were largely due to reflection from rough or hilly country, and when we went to work at Cheltenham

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we naturally expected to find the strongest and most numerous echoes coming from the west and north. While we did observe plenty of echoes from these directions we were surprised to find that the most numerous and the strongest echoes almost invariably came from the south and east, in both of which directions lies the sea. It would appear to us apparent, after a careful study of this matter and an examination of hundreds of echoes, that the surface of the sea is an excellent medium (possibly due to its high refractive index) for throwing back these echo signals. We are not yet able to say whether this action differs in stormy weather from the action in calm weather.

TABLE I

NKF 18.5 Megacycles April 30, 1928

Time	EAST		SOUTH		WEST		NORTH	
	1st Group	2nd and 3rd Groups	1st Group	2nd and 3rd Groups	1st Group	2nd and 3rd Groups	1st Gr u	2nd and 3rd Groups
1600	0.0107		0.0094 0.0107		0.0115 0.0123		0.0104 0.0120	
1700	0.0110 0.0116 0.0125	0.0257 0.0276	0.0098 0.0118		0.0108			
1730	0.0102 0.0118	0.0230 0.0238	0.0144		0.0111			
1830				0.0174 0.0190	0.0106		0.0101 0.0110	
1900	0.0115 0.0122	0.0236 0.0261 0.0360 0.0370	0.0106 0.0112	0.0186 0.0255 0.0294 0.0345	0.0112		0.0116 0.0125	
1930	0.0120 0.0125 0.0141	0.0282 0.0306 0.0370 0.0410	0.0123		0.0148		0.0119	0.0286 0.0299
2000	0.0130 0.0130	0.0291 0.0334	0.0136 0.0143		0.0112 0.0115		0.0133 0.0147	
2030	0.0122 0.0125 0.0151	0.0288	0.0140		0.0120 0.0120		0.0152 0.0178	
2100	0.0187 0.0190	0.0293 0.0309	0.0189 0.0196		0.0148 0.0175	0.0258 0.0260	0.0195 0.0197	
2130	0.0181 0.0184 0.0188	0.0326 0.0330 0.0345	0.0198		0.0182 0.0198	0.0296 0.0342	0.0188 0.0201	
2200			0.0220 0.0246	0.0370 0.0392	0.0184 0.0190		0.0188 0.0196	0.0301
2230	0.0181 0.0187 0.0188 0.0205	0.0335 0.0370	0.0202 0.0245		0.0204 0.0217		0.0184	
2300	0.0152 0.0171 0.0182 0.0185 0.0190 0.0210	0.0351 0.0355 0.0361	0.0207 0.0208 0.0240	0.0291 0.0312	0.0189 0.0197		0.0200 0.0210	

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The first test at Cheltenham was made with a high power transmitter at the Naval Research Laboratory set on 18,500 kc. Table I summarizes the results of the observations on 18,500 kc taken on May 18, 1928. It will be seen that if one considers the results for any given wire there is a general tendency for the echo time to lengthen out as one passes from afternoon to evening with the longest time echoes much more numerous late in the evening. This record was begun at 1600 zone plus five time and completed at 2300, at which time echoes were still being received. The record also shows that more echoes were received from the south and east than from the west and north, and the film shows that these echoes were also averaging better

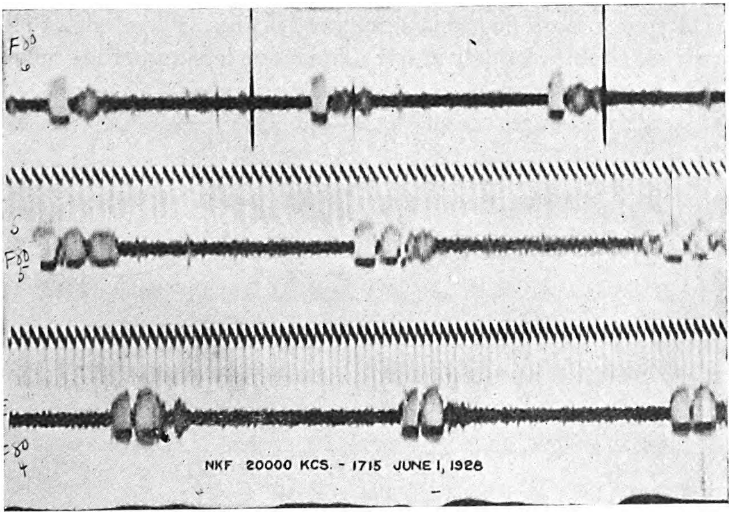

Fig. 4

intensity. We interpret those echoes whose times lie between 0.01 and 0.016 second to be, in general, signals returned from the first zone of reception which immediately follows the skip distance region. Since these echoes can be returned from either edge of this first zone of reception, it follows that they will be spread over a considerable time interval. At the same time there is no doubt but that, as the evening wears on and the effective height of the Kennelly-Heaviside layer becomes greater, this zone of reception moves outward, which tends to lengthen the echoes. Thus, we see zone 2 echoes, obtained earlier in the evening, falling at time intervals which would probably correspond to zone 1 at a later hour. From a consideration of the very shortest time echoes, which we assume to be reflected from the inner

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edge of the first zone of reception, we may deduce, for instance, that between the hours 1700 and 1800 the skip distance on this frequency was of the order of 1600 km.

If we refer this to the curves published by one of us,[2] we see that the effective height of the Kennelly-Heaviside layer at this hour as measured from the east wire observations was approximately 240 km. The west and north wires give about the same average result, but the south wire determinations would give us a lower figure; namely, about 200 km. This is a reasonable result. The early evening observations on various wires between timing intervals of 0.016 and 0.022 should probably be interpreted as reflected from the second zone of reception, whereas in the later observations, at least later than 2100, they are probably first zone reflections since few, if any, reflections of shorter intervals are simultaneously noted. The much less numerous reflections

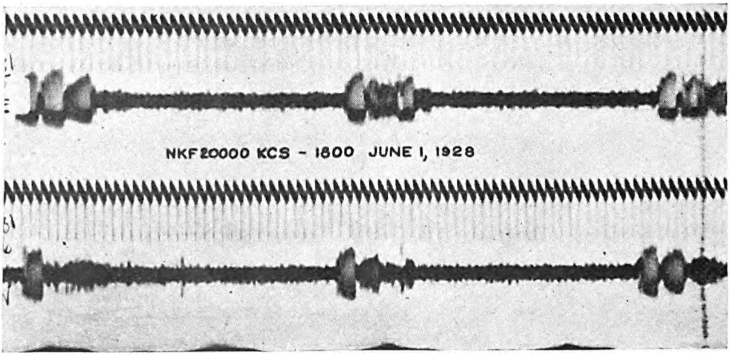

Fig. 5

of longer time intervals, extending in some cases out to over 0.04 of a second, are not readily explainable unless we assume that they are from zones beyond the second, some of which are sufficiently distant to give this time. The main thing, of course, is that an echo signal has to be of sufficient intensity to return to us after a round trip of over 12,000 km. If these echoes of the order of 0.03 to 0.045 second were always of very weak intensity one might be satisfied with this explanation, but the fact that they are sometimes extremely strong renders the tentative explanation we have given somewhat doubtful. While the general trend of the echoes is to come in from longer and longer time intervals as the evening wears on, this trend is decidedly not without its fluctuations, some of which will be spoken of later.

[2] Hoyt Taylor, Proc. I. R. E., 14, 521; April, 1926.

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The next observations were made on the same transmitter at the Naval Research Laboratory tuned to 20,000 kc. These observations were made on June 1, 1928 and are summarized in Table II. Figs. 4, 5, and 6 are reproduced from records made on 20,000 kc. They were

TABLE II
ECHO TIME
NKF 20 MEGACYCLES JUNE 1, 1928

Time	EAST		SOUTH		WEST		NORTH	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
1400	0.0204	0.0172 0.0196						
1500					0.0225	0.0190		
1600	0.0166	0.0166	0.0166	0.0166				
1700	0.0141 0.0148	0.0154 0.0156 0.0330*	0.0291*	0.0146 0.0310*			0.0179	0.0175
1800	0.0127 0.0132 0.0134	0.0134 0.0139 0.0146 0.0154 0.0270* 0.0280*			0.0161 0.0200	0.0161 0.0200 0.0335*	0.0132 0.0160 0.0300*	0.0132 0.0290*
1930	0.0172 0.0180 0.0186 0.0196 0.0315* 0.0360*	0.0204 0.0212 0.0216 0.0230 0.0385* 0.0390*	0.0198 0.0178 0.0198	0.0206 0.0201	0.0210	0.0212 0.0212	0.0176	0.0215
2000	0.0225 0.0410*	0.0233 0.0420*	0.0172		0.0188 0.0201 0.0391*	0.0400*	0.0177 0.0195	0.0196 0.0120
2100	0.0216 0.0234	0.0238 0.0246			0.0216	0.0250	0.0195	0.0207

* Second group echoes.

taken at 1715, 1800, and 2005 hours, and are herewith presented to show the way the time interval between signal and echo increases as the hour gets later.

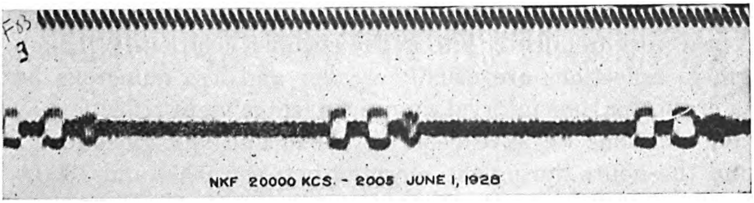

Fig. 6

In Fig. 4 we see the echoes almost overlapping the signal. In Fig. 5 the echoes overlap each other but are spread further out from the

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signal, and in Fig. 6 the signal with its two distinct echoes, one strong and one feeble and both of short time duration, is plainly distinguishable. The results of the observations on 20,000 kc are shown in Table II. We find again a great predominance of echoes on the east wire. One curious thing about the record is that the Kennelly-Heaviside layer appeared to drop in effective height between 1400 and 1800, after which it rose rapidly. The skip distance determinations for the hour 1800 would show a distance of 1900 km, which would correspond to an effective layer height of approximately 225 km, which is of the same order of magnitude as previously determined for 18,500 kc. This observation is based on the east wire. The north wire would give about the same height, but the west wire would give a skip distance of 2400 km corresponding to an effective layer height of approximately 250 km. This is contrary to what one would expect as the layer should be lower in effective height to the westward than to the eastward, at this hour of the day. However, there were very few observations on the west wire and possibly the reflection upon which the calculation was based was not the nearest possible reflection to obtain from the first zone westward. The reflections from the westward at that time were very weak besides being few. There is only one measurable reflection on the south wire upon which to base an observation, and this reflection would give somewhat greater height than on the east wire but not as great as on the west. The general tendency for the time intervals to increase as the day wears on is contradicted between 1400 and 1800, but is plainly in evidence from 1800 to 2100. This peculiar inversion in the apparent movement of the layer is evidenced in nearly all of our observations. The time at which it occurs is shifted towards later hours as we go from spring to summer. During the spring months reflections, especially on the north wire, would sometimes disappear late in the evening but during the summer months reflections even on as high as 20,000 kc would not disappear as late as 2300. Some of the longer time reflections would disappear very frequently late in the evening. Curiously enough, the afternoon reflections are usually weaker and less numerous besides being of shorter time interval than the average night reflection, and on several occasions we have been unable to find any reflections at all around the hours during the morning between 0900 and 1300. The explanation of this is not wholly obvious. It is true, however, that these short time echo signals are not of very great intensity, and that the absorption may be expected to be heavier in the daytime than it is in the evening. Normally we would expect echoes, although of weaker intensity, during the entire daylight period and lasting into the night

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until the Kennelly-Heaviside layer became high enough to cut these frequencies off entirely. It was noticed during the summer observations that whenever we got persistent echoes on the east wire late at night on the high frequencies it was generally possible to hear European stations on these same high frequencies whether we received them on fundamental or harmonics. Thus, when our local observations indicated a persistence of a moderately low layer level, the transatlantic observations indicated in general the same thing.

TABLE III
ECHO TIME
NKF 20 MEGACYCLES JULY 18, 1928

Time	EAST		SOUTH		WEST		NORTH	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
1545	0.0158 0.0174	0.0190 0.0206	0.0158	0.0167 0.0177				
1630			0.0175	0.0175				
1700	0.0177 0.0178	0.0207						
1730	0.0166 0.0167	0.0186 0.0187						
1745	0.0154 0.0175	0.0177 0.0204 0.0318*	0.0179					
1815	0.0169 0.0169	0.0181 0.0182			0.0152 0.0156	0.0177 0.0179	0.0167	0.0187 0.0188
1915	0.0156 0.0175 0.0177	0.0207 0.0215 0.0221 0.0368* 0.0380*	0.0164	0.0190 0.0295*				
2000	0.0185	0.0222	0.0155 0.0156	0.0191 0.0192 0.0375*				
2045	0.0188 0.0211	0.0217 0.0225					0.0157 0.0165	0.0208 0.0225
2100			0.0158	0.0208 0.0355*				
2130	0.0171 0.0177 0.0178	0.0188 0.0199 0.0203	0.0173 0.0175 0.0179	0.0172 0.0175 0.0176 0.0365*				
2145			0.0181 0.0185 0.0188	0.0191 0.0194 0.0197	0.0172			

* Second group echoes.

At this point in the investigation it was thought that possibly the nature of the antenna structure at the transmitter might have something to do with the echoes and to the fact that they were stronger from certain directions than others. The horizontal doublet was therefore replaced by a vertical half-wave doublet coupled to a feed line, but

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again the observations showed the same general distribution of echoes, the east wire being the favorite both by number and intensity, and following that the south wire. We conclude, therefore, that directivity from the transmitter has no particular influence on the number and strength of the echo signals, and in particular has no bearing on the fact that echoes were received better from over the sea than elsewhere.

About this time steps were taken to shorten the dot impulses at the transmitter to permit a sharper discrimination and measurement of the echo timing. Table III presents the results of the observations also on

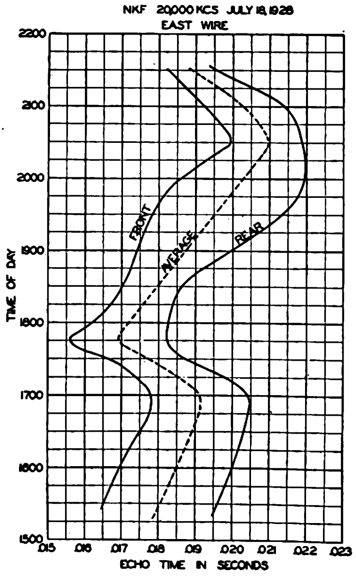

Fig. 7

20,000 kc obtained on July 18, 1928. Fig. 7 presents graphically the results on the east wire in which the echo signals can be presented in the form of two curves corresponding to measurements made on the front of the dot and the rear of the dot, respectively. From the very nature of it the echo signal has a tendency to spatter out a good bit so that it was thought wise to get measurements in both ways. It was thought that if a medium line was drawn between these two curves it would represent the variation in the skip distance and therefore the variation in effective layer height between the hours of 1530 and 2200. This curve shows again a diminution in skip distance and effective layer height in the early evening for this observation taken in the

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summer, coming somewhat earlier than for observations taken earlier in the year. A second apparent surge in layer height is evident in this case around the hour 2030. Effects of this nature were so persistent in our records (only part of which are reproduced in this paper) that it is perhaps worth while to present a summary of results in the form of the curves shown in Fig. 8. This figure plots the average time interval observed against the hour of the day. This average time interval is related to certain distances which would be double the skip distance.

Curve 1 taken on 18,500 kc on April 30th shows the first knee or bend in the curve at the time 1830. Curve 2 taken on June 1st at 20,000 kc, of course, shows greater skip distances, but it also shows the knee in the curve occurring at 1800, whereas curve 3 taken on 20,000 kc on July 18th shows greater initial skip distances, less variation in the signal throughout the night, and the knee of the curve occurring at

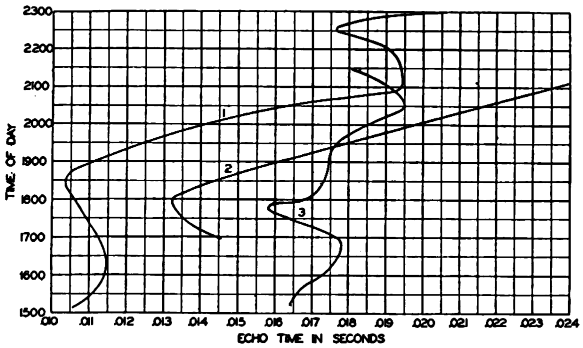

Fig. 8

about 1745. It is evident that this apparent preliminary drop in the effective layer height or decrease in the skip distance from afternoon to early evening is a real effect occurring for both the frequencies observed but differing insofar as it occurs earlier in midsummer than in spring, and is therefore probably related to sunset effects. The subsequent variations which occur in curve 1 and curve 3 are probably due to some turbulence in the layer, the mechanism of which is at present entirely in the dark.

On July 26th observations on short dots on 20,000 kc were taken at Cheltenham from 1000 on. No reflections were observed on any of the wires until 1500, and then on the south and east wires, but too weak to photograph properly. At about 2000 the echoes began to be of normal strength and at the same time extremely good round-the-world signals were noted. Fig. 9 shows the type of record obtained earlier in the day when neither round-the-world nor echo signals were present.

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Fig. 10 shows this sort of record obtained after 2000. The signals marked S_1, S_2, S_3, and S_4 are the ground waves. R_1, R_2, R_3, and R_4 are short time echoes. AS_1 and AS_2 are round-the-world signals showing the typical timing interval of 0.14 of a second, and A_2S_1 is a signal which has made two trips around the world, being 0.28 of a second behind the signal S_1. It is plainly not a short time echo, and equally plainly the timing interval is not at all right for it to have made one trip around the world. This rather unusual record shows these three types of phantom signals very well.

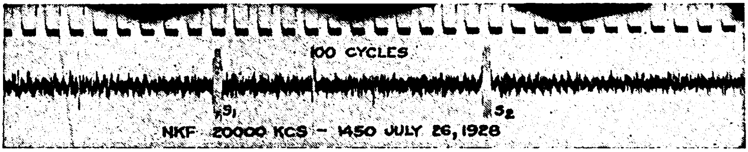

Fig. 9

From a series of observations on the front and rear of the dots on round-the-world signals, the average time interval measured on the front of the dot is 0.1386 second and on the rear of the dot 0.1391 second, giving an average time interval of 0.1389 which checks well with the average round-the-world timing intervals in the earlier paper already referred to. The twice around-the-world signal shows a timing

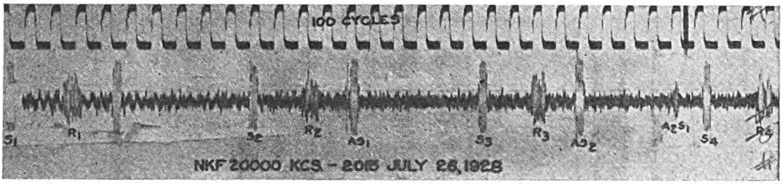

Fig. 10

interval of 0.2772. Based on this timing interval we can calculate an effective average layer height of 265 km. Table IV shows the echo signals as observed on this rather unusual night. We may conclude from a study of these echoes that the center of the first zone of reception was distant about 3600 km, and that the inner edge of the zone was approximately 3300 km distant, which would lead to an effective layer height in the neighborhood of 280 km, practically the height which cuts off permanently the use of the frequency 20,000 kc. In other words, both the absence of echoes and the extremely long time

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interval of the shortest echoes indicate the same thing; namely, an unusually high layer. Since this condition was apparently present also during the daylight hours it must be considered, at this time of the year especially, as decidedly abnormal. It is noteworthy that during the hours 0900 to 1400, when we ordinarily hear without difficulty the Rocky Point group of the R.C.A. by means of their echo signals, they

TABLE IV
ECHO SIGNALS 1000–2200
NKF 20 MEGACYCLES JULY 26, 1928

Time	EAST WIRE	
	Front	Rear
1700	0.0248 0.0240	0.0262 0.0253
2015	0.0220 0.0221 0.0228	0.0258 0.0254 0.0257
2145	0.0229	0.0245

Note: Echoes received only on east wire, and not strong enough to photograph until 1700.

were conspicuously absent. Some European stations in the high-frequency band were received with excessive fading. The first signals from the R.C.A. group at Rocky Point by echo were heard at 1400 very weakly. All indications therefore point to a decidedly abnormal day, the effect holding over into the night. During the evening the Rocky Point group came in at more than normal signal strength, and European stations were of excellent intensity. Nevertheless, it can be inferred that the layer remained higher than normally during the evening hours.

Some attempts were made to study echoes on still higher frequencies, but at the time this work was being carried on suitable transmitters and receivers were not available. It is highly advisable in this work that the transmitter be of extremely constant frequency and the receiver of more than ordinary stability. Since that time a different type of study has been carried out which shows that echo signals during the daylight hours exist on frequencies up to 30,000 kc and possibly higher. The upper limit is not yet known. Photographic studies have not yet been completed, so that the exact timing of these signals is also not yet known. It is known, however, that the skip distance increases with the frequency more or less as might be expected. It is also perfectly clear that it is not quite safe to extrapolate the general theory in order to forecast what may happen on frequencies above 25,000 kc until we have more detailed information as to the

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electron concentration in the layer and the distribution thereof. In other words, we find inconsistencies between effective heights of the layer as measured, say on 20,000 kc and as deduced from the frequency at which all echoes disappear. The effective layer height deduced from observations made in the 20,000 kc band might indicate a height which ought to cut off completely 28,000 kc, but actually at the same time we are able to observe certain echoes on 28,000 kc, indicating that it is not completely cut off although it has a very long skip distance. This clearly indicates that certain corrections and additions based on new information as to layer structure must be taken into account before we can definitely describe what has happened in these extremely high-frequency bands.

We see nothing in our latest observations to cause us to change our opinion that short time echo signals are returned not from a point in space away from the earth, but are thrown back from the surface of the land or sea by way, of course, of an intermediate reflection from the layer.

As previously pointed out, the echo signals showing relatively large retardations may be explained as signals returned from zones of reception beyond the first, except that their extraordinary intensity at times makes us feel that this explanation cannot be accepted without at least giving consideration to the mathematical possibility of their being of such an electron distribution that abnormal retardations of velocity may occur, so that even these longer time echoes could still be returned from the first zone although by rather abnormal paths in the layer and not at all unless certain conditions as to electron distribution in the layer are fulfilled. At present there seems to be no way, experimentally, of deciding between these two possible explanations.

Concerning the drop in effective height near the sunset hours, something further may be said. The first and immediate effect of approaching sunset will be to cool the atmosphere, causing a general drop in the layer height. A little later all ultra violet radiation will be cut off from the high layers and re-combination will set in causing the layer, which is always normally lower after sunset, to show a greater effective height because of the reduced number of electrons. It is then perfectly consistent that the approach of sunset could first bring on a small drop in the effective height of the layer due to cooling of the lower levels of the earth's atmosphere which constitute the supporting pillar upon which exists the upper layer. This would be a real drop in both effective and actual heights. Following this comes the re-combination in the absence of ultra violet in the high levels, which causes a thinning out of the electrons, leading in time to the subsequent and more

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normal rise in effective height, although the actual height may still remain low. This seems a reasonable explanation of the effects we have observed and their variation with the time of the year. Later on in the evening where we have to do with fairly high effective layer height, perturbations due to high atmospheric winds of unusual magnitude may cause turbulences and fluctuations such as are shown in some of our observations.

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GROUP-VELOCITY AND LONG RETARDATIONS OF RADIO ECHOES*

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Summary—*Van der Pol's hypothesis that group-velocity may account for the retardation of echoes observed by Stoermer is analyzed. It is shown that only under very special circumstances can the electron-distribution be proper. A favorable condition is obtained if the refractive index decreases exponentially with the height. It is shown that by slightly varying the electron-distribution anomalous results for skip-distances should follow. It is suggested that the echoes observed by Stoermer and van der Pol were splashes of the same echo focussed accidentally on a favorable patch of ground.*

ECHOES of signals with very long retardations up to 15 seconds have been observed by Stoermer and van der Pol. Explanations of these remarkably long retardations have been given by Stoermer, van der Pol,[1] and Appleton.[2] The explanation of van der Pol seems to be the most concrete one. His idea is that the radio wave may penetrate into the region of the atmosphere where its phase-velocity is very high and consequently the group-velocity is low. According to van der Pol, the very long retardations are, therefore, due to the group of waves constituting the dot or dash of the signal going by a path along an appreciable portion of which the velocity of the group is very small.

The implications involved in this explanation can be illustrated graphically by means of a theorem stated by Breit and Tuve. It has been proved there that if the path of the ray is ABC (see Fig. 1) then for short waves the time taken by the signal to go from a point A on the ground to another point C, also on the ground, is equal to the time which the signal would take to travel in empty space along the path constituted by the tangents AD, CD. The retarding effect of the electrons in the upper regions of the atmosphere is, therefore, such as to retard the arrival of the signal, the path ADC being always longer than ABC.

If now Stoermer's echoes are to be explained by group-velocity considerations, this simply means that the point D must be moved to a very great distance comparable in fact to the distance to the moon.

* Dewey decimal classification: R113.6. Original manuscript received by the Institute, March 26, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] *Nature*, **122**, 878–879, 1928.
[2] *Nature*, **122**, 879, 1928.

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Supposing that the Kennelly-Heaviside layer is horizontal, the signal must leave the transmitter almost vertically and come down to the receiver also almost vertically. The electron-distributions which have been considered as likely or possible ones do not make it possible to have such paths without moving the point B up to an unreasonably large height. Thus, for instance, if the electron-density increases uniformly with the height, the path ABC is a parabola and the ratio of the height of D to the height of B is always 2. We cannot explain the very long echoes, therefore, by retardations due to small group-velocity by this electron-distribution unless we allow the signal to reach a height which is, say, half the distance to the moon. This is just as unreasonable as allowing it to go to the moon itself.

If we are to explain the long echoes as an effect of low group-velocity, we must find, therefore, electron-distributions which will make the ratio of the "effective height" of D to the actual height of B very large. We see from the above example that the electron-distribution must be of a special sort and that the simplest distributions do not answer the purpose. We proceed to investigate the relation between the effective height and the actual height as determined by the nature of the electron-distribution.

Let the refractive index at a height y above the lower boundary of the layer be $\mu(y)$. By Snell's law $\mu(y)\sin\theta=\sin\theta_0$, so that letting x be the distance traveled by the signal in a horizontal direction

$$dx=((\mu(y)\sin^{-1}\theta_0)^2-1)^{-1/2}dy \tag{1}$$

is the differential equation of the ray. In this formula θ_0 is the angle which the ray makes with a vertical line at the transmitter or at the

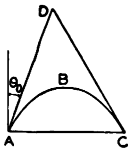

Fig. 1

receiver (see Fig. 1). Referring to the coordinates of B as X, Y, we have, letting $d\mu/dy=\mu'$,

$$X=\int_{x=0}^{\mu}[(\mu(y)\sin^{-1}\theta_0)^2-1]^{-1/2}dy=\int_{\mu=\sin\theta_0}^{1}\frac{-(\mu')^{-1}d\mu}{\sqrt{\mu^2-\sin^2\theta_0}}\sin\theta_0 \tag{2}$$

and

$$h=X\sin^{-1}\theta_0 \tag{3}$$

where X is, therefore, half the range of the signal in the reflecting layer

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and h is the length of AD or the effective height as observed by the retardation of the echo. In formula (2) we have transformed the expression into an integral in terms of μ, the refractive index itself. This is convenient because by so doing we fix the limits of integration as $\sin\theta_0$ and 1 and can see through the dependence of X on the form of $\mu(y)$.

In order to obtain very large effective heights we must arrange $\mu(y)$ in such a way that for a reasonable X, say, 100 or 500 miles, we should get a very small θ_0. We take, therefore, various forms for μ' as a function of μ and arrange the results in order according to powers of μ. Let

$$\mu' = -a^{-1}\mu^{-n}, \text{ i.e., } \mu = [1-(1-n)ya^{-1}]^{1/(1-n)}. \qquad (4)$$

By (2)

$$X = an^{-1}\sin^{1-n}\theta_0 \int_{\sin^n\theta_0}^{1} dx/\sqrt{1-x^{2/n}} \qquad (5)$$

Using (3), (4), (5) we construct the following table

n	μ	Y	X
-1	$\sqrt{1-2y/a}$	$(a/2)\cos^2\theta_0$	$a\sin\theta_0\cos\theta_0$
0	$1-y/a$	$a(1-\sin\theta_0)$	$a\sin\theta_0\log[(1+\cos\theta_0)/\sin\theta_0]$
†1/2	$(1-y/2a)^2$	$2a(1-\sin^{1/2}\theta_0)$	$2a\sqrt{\sin\theta_0}\{\sqrt{8/\pi}\Pi^2(1/4)-\sqrt{\sin\theta_0}\}$
†2/3	$(1-y/3a)^3$	$3a(1-\sin^{1/3}\theta_0)$	$(3a/2)\sqrt[3]{\sin\theta_0}\{3^{5/2}2^{-4/3}\pi^{-1}\Pi^3(1/3)-\sin^{2/3}\theta_0\}$
1	$e^{-y/a}$	$a\log\sin^{-1}\theta_0$	$a(\pi/2-\theta_0)$
2	$a/(n+a)$	$a(\sin^{-1}\theta_0-1)$	$a\cot\theta_0$

† The values for $n=\frac{1}{2}$, $n=\frac{2}{3}$ are approximate for $\theta_0 >> 1$.

A tabulation of h is not necessary, it being obtained directly from the last column and (3).

The case $n=1$ is of particular interest. For small θ_0, $h=\pi a/2\theta_0$, $Y=a\log\theta_0^{-1}$, $h/Y=(\pi/2)/(\theta_0\log\theta_0^{-1})$. If $\theta_0=10^{-5}$, $\log\theta_0^{-1}\cong 10$, $h/Y\cong 1.4\times 10^4$. Thus for directions very close to the vertical one could have retardations to a height of $1.4\times 10^4 Y$. Taking $Y=186$ miles, we would get a retardation of 28 seconds. A retardation of 3 seconds would correspond to $\theta_0=10^{-4}$, and if we should allow Y to be five times greater than we have taken it θ_0 could be as alrge as 1/2000 radian $\cong$1/40 of a degree. The distribution of electrons which would give a decrease of μ with height according to the law $e^{-y/a}$ makes it possible, therefore, to explain very retarded echoes provided the energy sent out nearly vertically by the antenna is sufficiently great. The requirement on the

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energy is rather stringent because an echo which is at all clear-cut must correspond to a sharp range of values of θ_0. The range of angles corresponding to a definite echo is, therefore, at the most 10^{-4} radian which gives at a distance of 100 km a spread of the beam of not more than 10 m. Since the wavelength used in the experiments is 31 m, the path has to be at least 300 km from the ground to the layer before we can consider such an angle as at all definite. Even though it is very difficult to imagine that at the same time the layer should be sufficiently high, the distribution of electrons just right through a height of about 800 miles and the energy sent vertically by the antenna should be sufficient, we may admit a possibility of $\mu = e^{-y/a}$ giving the very long retardations. The signals should be very erratic and very faint.

That they should be erratic can be seen further by considering other values of n. For small θ_0 and $n=2$, $Y=a\theta_0^{-1}$ and $h=a\theta_0^{-2}$; $h/Y=\theta_0^{-1}$. However, if $\theta_0 \leqq 10^{-4}$, then $a=10^{-4}Y$. Thus if $Y=300$ km, a is only 30 m. This means that the refractive index would drop from 1 to 1/2 in a wavelength so that true refraction could hardly occur. The situation can be saved by granting the possibility of larger Y which will increase θ_0 and a. This case is also a possibility but subject to the same limitations as for $n=1$.

For $n=0$, $h=a \log (2/\theta_0)$, $Y=a$. This is unfavorable since quite unreasonably small θ_0 is required. For $n=1/2$, $h=2\sqrt{8/\pi}\Pi^2(1/4)/\sqrt{\sin\theta_0}$, $Y=2a$. The dependence of h on $\sqrt{\sin\theta_0}$ is unfavorable. For $n=2/3$, h is proportional to $(1/\sin\theta_0)^{2/3}$. This is better than $n=1/2$, but not as good as $n=1$ or 2. The case $n=-1$ gives even no purely mathematical possibility of getting large effective heights. This is the well-known case of the electron-density increasing uniformly with the height giving parabolic rays mentioned before. We may conclude, therefore, that the group-velocity explanation is a possible one disregarding absorption, and that it corresponds to such an electron-distribution for which $\mu = e^{-y/a}$.

The possibly detrimental effects of absorption have been considered by E. V. Appleton[2] and L. H. Thomas.[3] They undoubtedly point out a serious difficulty. It must be remarked, however, that the calculations of Thomas on the mean free-path correspond to an effective area of collision for electrons of the order of 2×10^{-5} cm, which is high compared even with atomic dimensions. It may be questioned, therefore, whether his calculation is to be interpreted as a change of phase of the forced electronic vibrations or simply as a cumulative effect in the scattering of electrons. It seems safest, therefore, to let the possibility of relatively low absorption in the high regions remain open,

[3] *Nature*, **123**, 166, 1929.

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particularly since the electron-distributions used above lead to reasonable energies disregarding absorption only if we let the actual height Y be large, say above 600 kilometers.

Focussing Effects

According to the observations of Stoermer and van der Pol, there is a considerable number of echoes arriving with the same retardation at Oslo and Eindhoven. If a direct path to each receiver were traced, the retardations would naturally be different. We prefer, therefore, to suppose that the observed echoes were splashes of one and the same echo heard by the two observers. This seems possible for the case $n=1$, for if the height of the lower boundary of the layer above the surface of the ground is a, all rays with small θ_0 are focussed at a distance πa as shown in Fig. 2.

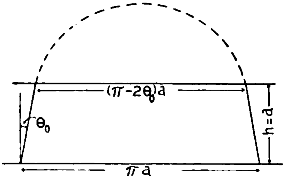

Fig. 2

Similarly for case $n=2$, the range is $2a \cot \theta_0 + 2h \tan \theta_0$. Here there is no focussing for small θ_0, and in fact if $a>h$ the range is seen to decrease with θ_0 for a considerable range of values of θ_0, the minimum being at $\tan \theta_0 = \sqrt{a/h}$ corresponding to a range of $4\sqrt{ah}$.

From the point of view of focussing, therefore, the distribution $n=1$ seems again the most likely one.

It will be observed that the variation of μ and y is not very different for $n=2/3$, $n=1$, $n=2$. We would expect, therefore, that the presence of long echoes will be connected with anomalies in general radio transmission of the same nature as is usually observed during magnetic storms. The case $n=2$ as we have seen gives smaller ranges for more oblique incidence which is just the opposite of what is usually supposed to take place. Such a condition would result in breaking up the regular transmission conditions in which oblique incidence on the layer gives larger ranges than normal incidence.

Assuming the correctness of van der Pol's explanation, we should expect changes in skip-distance to occur before or after the long echoes, and in particular we expect that at such times oblique incidence on the layer will give shorter range than normal.

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Proceedings of the Institute of Radio Engineers
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FURTHER STUDIES OF THE KENNELLY-HEAVISIDE LAYER BY THE ECHO-METHOD*

By
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Summary—*Recent observations of the Kennelly-Heaviside layer by the echo-method are described. Multivibrator-modulation was used, giving extremely sharp "peaks" on 4,435 and 8,870 kc. Practically all of the observations were made on the former frequency, as 8,870 kc skipped over the receiver, which was very near the transmitter. Two 24-hour series of observations showed a marked diurnal-variation in the effective height of the layer and in the echo-pattern received for each transmitted "peak." The echo-pattern shows multiplicities during the day and evening, but becomes very complex at night. A few observations made during the magnetic disturbance of October 17–19, 1928, showed an unusually great effective height and a change in the echo-pattern. Daytime heights for a number of days during the autumn of 1928 are given.*

General Method

SOME recent experimental results obtained in studies of the Kennelly-Heaviside layer by the echo-method are reported in this paper. The method has been described in earlier publications,[1] and consists in the oscillographic recording at a receiver of the ground-wave and echo-pattern from the layer of a transmitter modulated to emit very short pulses or "peaks," separated by intervals of no emission, during which the echoes are recorded. The receiver arrangements were practically identical with those previously described,[1] and the modulation of the transmitter was accomplished by the use of unbalanced multivibrator-circuit.[2]

The transmissions, as before, were from the Naval Research Laboratory at Bellevue, Anacostia, D. C., and grateful acknowledgment is due to Captain E. G. Oberlin and to Messrs. A. H. Taylor, L. A. Gebhard, M. H. Schrenck, and others there for their continued and cordial cooperation in the carrying out of this work. We also wish to thank our colleagues, G. Breit, whose continued association with the work has contributed so largely to it, and J. A. Fleming, whose enthusiastic support has made it possible.

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, May 22, 1929. Abstract presented before joint meeting of the Institute and International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, May 15, 1929.

[1] G. Breit and M. A. Tuve, *Phys. Rev.*, **28**, 554; September, 1926.
[2] M. A. Tuve and O. Dahl, Proc. I. R. E., **16**, 794; June, 1928.

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TRANSMITTERS

Two 20-kw transmitters, crystal-controlled by separate crystals and operating on 4,435 and 8,870 kc, were modulated by the same multivibrator set. Exactly simultaneous "peaks" of very short duration

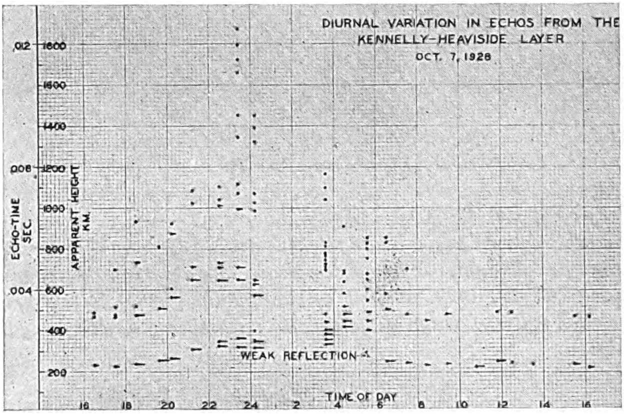

Fig. 1—Diurnal variation in echoes from layer, October 7–8, 1928.

(0.0002 sec., or less), spaced 0.1 to 0.01 sec., were consequently emitted on the two different transmission frequencies. Before the actual

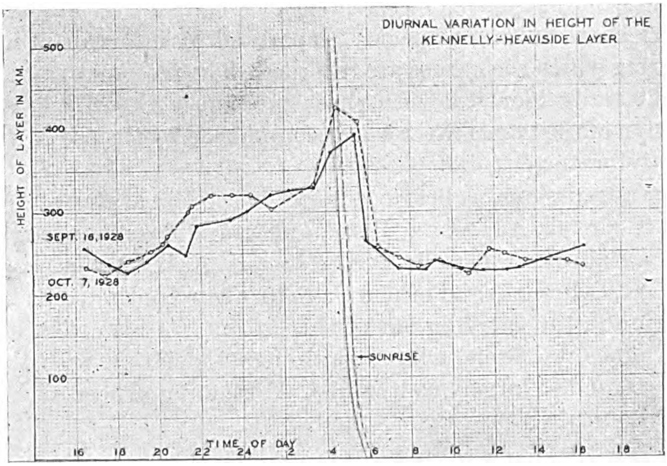

Fig. 2—Diurnal variation in height of layer, September 16–17 and October 7–8, 1928.

transmission experiments were begun, considerable time was spent at the transmitter, oscillographing the emitted wave-shape with various

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adjustments, to insure with certainty that no circumstances of altered voltages or other adjustments at the transmitter could give rise to secondary "peaks" or other misleading changes in emitted wave-shape. With two transmitters simultaneously modulated in this way it was hoped that simultaneous records of the effective heights of the layer for the two transmission frequencies might be obtained. Although the ground-wave on 8,870 kc is absorbed in a very few miles from the transmitting station (with this modulation it is too faint to record with our present receiver only 7 miles from the transmitter), the 4,435-kc ground-wave provides a reference point. However, it has been our experience that the 8,870-kc sky-wave "skips" over our receiver at prac-

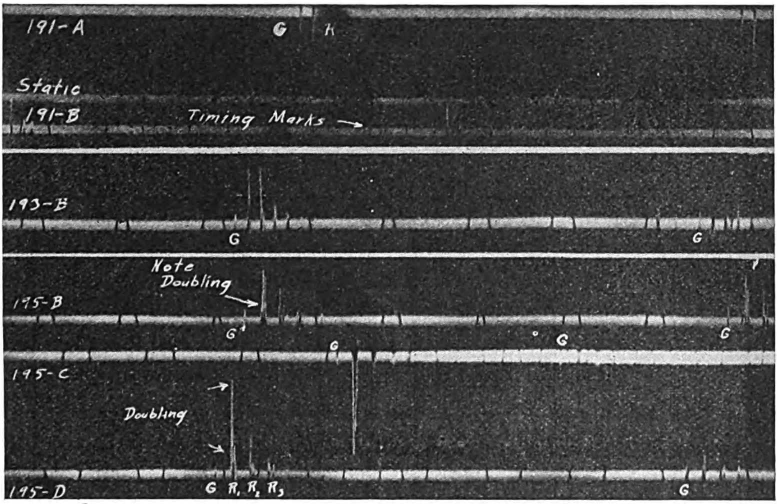

Fig. 3—Typical normal-day variation in echo-pattern, October 6–7, 1928: 191-A and 191-B daytime at $14.^{h}7$ October 6; 193-B just after sunset at $18.^{h}5$ October 7; 195-B, 195-C, and 195-D showing multiple reflection and scattering at $22.^{h}4$ October 7.

tically all times, and a double recording receiver has not yet been set up here for this reason. The 8,870-kc wave has been received stro gly on two occasions, both times just preceding times of considerable magnetic activity (Sept. 18 and Oct. 18, 1928), but the only pictures obtained showed single "peaks," the absence of a ground-wave preventing any measurement of height. This erratic behavior is qualitatively supported by observations in previous years. These observations are being continued and extended as far as possible, however.

After the transmitters were checked as described, and the tests here reported were begun, a number of other laboratories were notified of the

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schedules and invited to observe the transmissions. Simultaneous observations at different points, giving data for various angles of incidence at the layer, must eventually lead to results of value to our knowledge of the electron-distribution in the upper atmosphere. Messrs. G. W. Kenrick and C. K. Jen, of the Moore School of Electrical

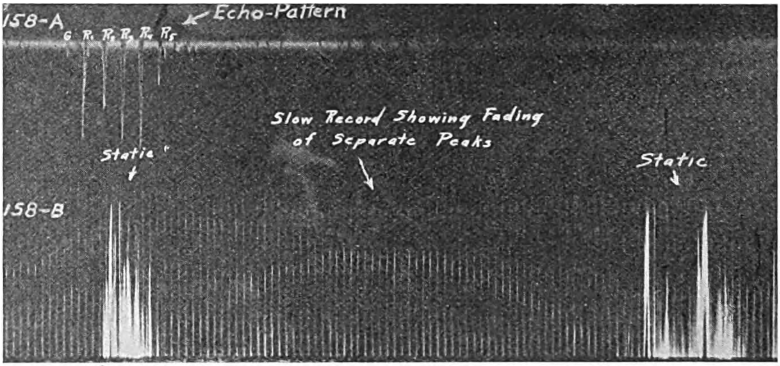

Fig. 4a—Record (158-A) at 3.^{h}2 September 17, 1928, showing five multiple reflections and slow-speed record (158-B) made just afterwards showing fading of separate peaks.

Engineering, University of Pennsylvania, Philadelphia, have already published their observations, made on the test of October 7–8, 1928.

24-Hour Diurnal-Variation Schedules

Some rather interesting and unexpected results were obtained when the signals were observed during two 24-hour schedules, September

Fig. 4b—Records (196-C and 196-D) at 23.^{h}5 October 7, 1928, showing four multiple reflections.

16–17, and October 7–8, 1928. Although no records could be obtained on 8,870 kc, as explained above, the 4,435-kc signals showed marked diurnal-variation in two important characteristics, echo-pattern and effective layer-height.

The echo-pattern is characteristic of the time of day at which the observation is made, and the pattern goes through a complete cycle in

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24 hours. Fig. 1 shows schematically the variation in the echo-pattern (4,435 kc) during the 24-hour schedule of October 7–8. The schedule of September 16–17 showed the same patterns. The intensities of the various peaks were only roughly compared, although they were in general much stronger at night than during the daylight hours, and only three gradations of intensity are indicated in the figure. The longer lines represent peaks of amplitude three to ten times that of the ground-wave, the shorter lines represent those about equal to the ground-wave, and the dots represent the still smaller (although always definite) peaks. Since the amplitudes of the various peaks varied independently and sometimes rapidly, intensity values are of very dubious worth when taken over the comparatively brief period of one or even several film exposures. The patterns shown schematically

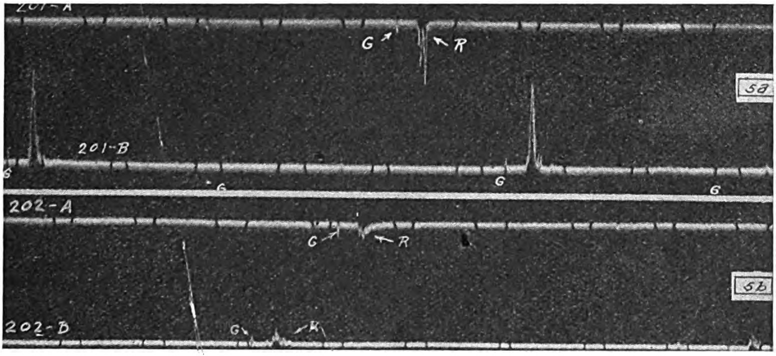

Fig. 5—Typical normal-day variation in echo-pattern October 8, 1928: 201-A and 201-B at 4.h5, reflection from a high layer with great scattering and no multiplicity; 202-A and 202-B at 5.h6, about sunrise, weak signals, echo from layer at daytime height barely visible.

in Fig. 1 are typical single patterns (due to a single "peak" at the transmitter, i.e., following a single "ground-peak" on the film at the receiver) for the different times of day; each pattern shown is typical of a considerable number of patterns recorded at the time indicated. The transmitters were operated 15–20 min. during each hour, and usually four or more full-length exposures at different receiver sensitivities were made during each transmission. The film-speed was about 200 cm per sec. and the films were about 150 cm long. These long films were found to be of great advantage in analyzing the records. The multivibrator at the transmitter was set to give from 10 to 50 "peaks" per second, so each trace recorded a number of successive signals. This made it possible to identify a repeating echo-pattern which could be associated definitely with each signal, eliminating any chance of con-

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fusion due to static or receiver noises, and also giving some indication of the amplitude variations of the various peaks. The latter variations were more or less irregular but in general were of periods greater than one sec., and show more clearly on the few slow records which were taken. (See Fig. 4*a*, trace 158-B). Typical examples of the oscillograph-records, showing various echo-patterns, are shown in Figs. 3 to 5. The accuracy of measurement is about ±10 km, and two peaks must be separated by about 40 km (apparent height; see Fig. 1) to be completely resolved.

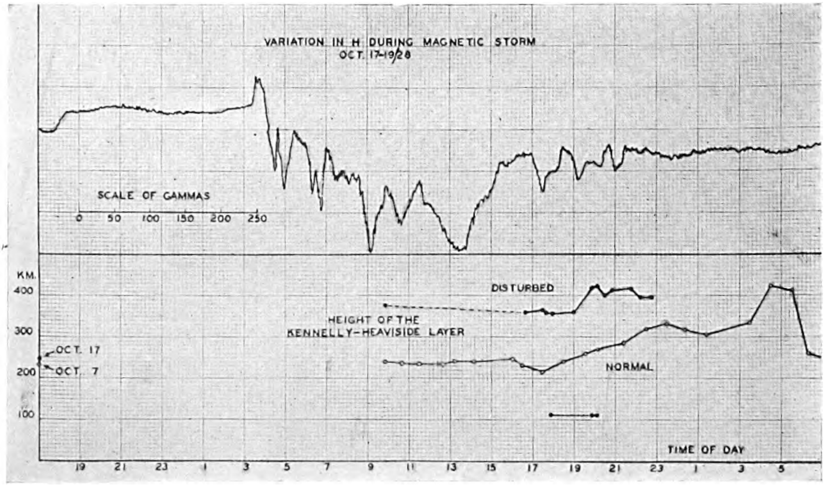

Fig. 6—Variations in horizontal intensity October 17–19, 1928, for magnetic storm recorded at the Cheltenham Magnetic Observatory and in observed height of layer for disturbed period (solid circles) October 17–18, 1928, and for normal period (open circles) October 7–9, 1928.

Several outstanding features of the results shown in Fig. 1 may be indicated. During the daylight hours there is usually at least one "reflected peak." A second often appears, although it is usually weak, and its retardation time is twice that of the first to within the errors of measurement. This multiplicity was first observed here a year ago.[3] A somewhat similar multiplicity was observed by R. A. Heising.[4] After sunset more and more echoes are observed; both this fact and the increase in amplitudes suggest decreased absorption in the layer. The peaks begin to appear in groups, each group occurring at an approximate multiple of the echo-time to the first reflected peak, although

[3] G. Breit, M. A. Tuve, and O. Dahl, Proc. I. R. E., **16**, 1236; September 1928.
[4] Proc. I. R. E., **16**, 75; January, 1928.

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multiplicities for separate peaks are usually not exact. The separation of the peaks is greater and the amplitude of individual peaks smaller for the higher order "reflections." The grouping suggests multiple reflection between the layer and the earth, and the "splitting" in each group may possibly represent successive splitting on each reflection into separate polarized components, but this can hardly explain the very great splitting which occurs in the early morning hours. From midnight on this "splitting" becomes more and more pronounced, the peaks occur in unresolved groups, the higher-order reflections become too weak to record, and the multiplicity is gradually lost. At sunrise the

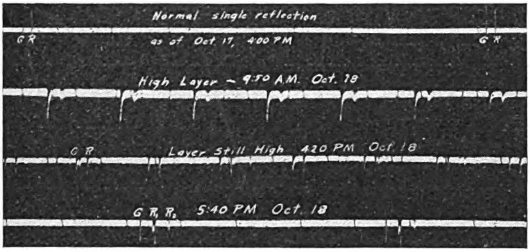

Fig. 7—Typical echo-patterns, October 18, 1928.

echo-pattern changes rapidly back to that typical of the daytime hours. An interesting feature was that a weak echo was observed from a layer at approximately the daytime height even before the echoes from the higher layer ceased. Since these heights are not multiples, it suggests that a layer at the daytime height is being formed below that from which the principal reflections occur during the night. The sunrise

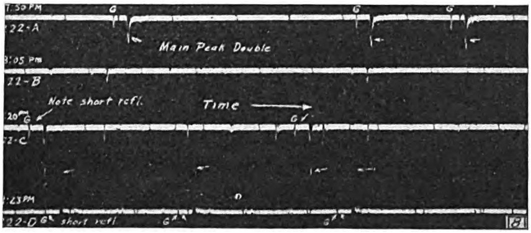

Fig. 8—Typical echo-patterns, October 18, 1928.

period will be subjected to intensive study before conclusions are drawn on the basis of such observations. Observations on various frequencies should show if there is an actual stratification of the layer.

The approximate multiplicity of the echo-time for the first, second, and higher-order reflections leads naturally to the picture of wave-

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groups traveling up and down a number of times between the layer and the earth's surface, although as yet we do not commit ourselves definitely to this view. However, if the echo-time to the first reflected peak be taken as a measure of the effective height of the layer, this quantity shows the diurnal variation illustrated in Fig. 2, where the values for the two 24-hour schedules are plotted. The steady day values, the slow rise during the evening, and the very sudden drop at sunrise are perhaps the most significant features. The time at which the sun's rays first appear (tangential) at different heights above the surface of the earth is roughly indicated by the transverse curves.

Magnetic Storm Observations

It may be of interest to include here a brief mention of some observations obtained on the day of a severe magnetic disturbance, October 18,

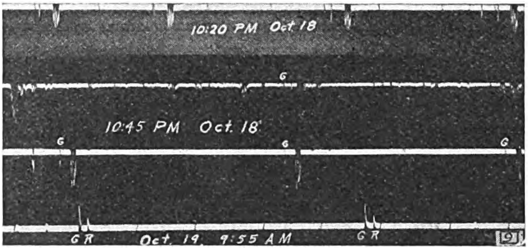

Fig. 9—Typical echo-patterns, October 18, 1928.

1928, although these observations are also reported elsewhere.[5] The measurements of height obtained on this day are shown in Fig. 6, with the diurnal curve of October 7 for comparison. The magnetogram for the day is also shown (courtesy of U. S. Coast and Geodetic Survey, Cheltenham, Md., magnetic observatory). The layer height was again normal on the morning of October 19. Typical echo-patterns (not retouched) are shown in Figs. 7, 8, and 9.

The observations obtained during the disturbance of October 17–19 were notably different in three respects from the "normal" ones obtained previously on undisturbed days: (1) the layer was abnormally high, as shown in Fig. 6; (2) an unusual short-time echo was observed (Figs. 6 and 8); and (3) the echo-pattern during the evening did not show the many groups of echoes otherwise observed at this time of day. Reflections from a height of about 100 km have been observed before,[6]

[5] L. R. Hafstad and M. A. Tuve, *Terr. Mag.*, **34**, 39–44, 1929.

[6] G. Breit, M. A. Tuve, and O. Dahl, Proc. I. R. E., **16**, 1236; September, 1928. O. Dahl and L. A. Gebhard, Proc. I. R. E., **16**, 290; March, 1928.

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but this was the only time they were observed by us during the autumn of 1928. The echo-patterns during the evening of October 18 resembled those of the "normal" early morning hours, when the layer-height was similar, as illustrated by Fig. 10.

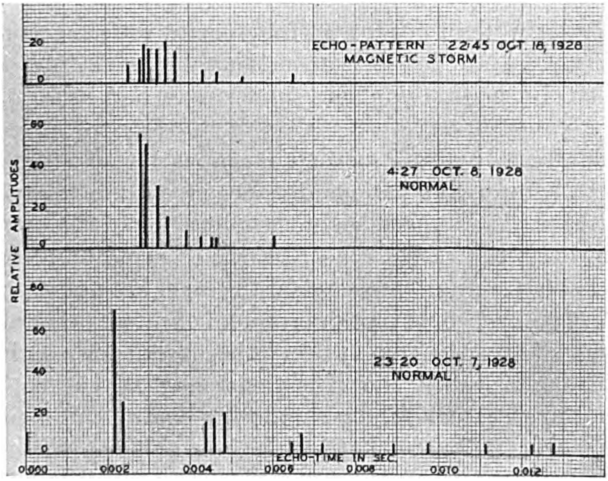

Fig. 10—Specimen echo-patterns during magnetic storm October 18, 1928, and during normal days October 7 and 8, 1928.

TABLE I

EFFECTIVE DAYTIME LAYER-HEIGHTS, AUTUMN 1928

Date	Time		Effective heights
1928	h	m	km
Jul. 14	11	00	229
Jul. 16	10	15	235
Sep. 12	13	50	246
Sep. 16	16	20	241
Sep. 26	16	35	235
Sep. 27	10	00	234
Sep. 28	14	18	245
Oct. 1	9	40	252
Oct. 3	9	52	245
Oct. 3	14	44	245
Oct. 6	9	53	252
Oct. 16	14	33	253
Oct. 16	16	15	243
Oct. 17	9	40	375
Oct. 19	9	55	252
Oct. 20	14	30	235
Oct. 26	9	55	225
Oct. 26	14	59	232
Oct. 29	10	00	225
Nov. 4	10	00	232
Nov. 5	10	00	220
Nov. 7	10	00	225
Nov. 10	9	40	226
Nov. 17	9	50	232

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Discussion

This paper is published as a report of experimental results. The writers prefer to postpone any extensive discussion of the significance or interpretation of these results in terms of electron-distribution and other characteristics of the ionized layer until further data are available, particularly observations at frequencies differing considerably from 4,435 kc, and, if possible, at various distances from the transmitter. Such observations are being undertaken here as far as facilities permit. It seems probable that a complete series of approximately simultaneous tests by this method using various transmission frequencies and recorded at various distances from the transmitter will give a fairly complete knowledge of the ionization of the upper atmosphere. However, the varied echo-patterns received indicate that the reflection (and refraction) processes at the layer are not simple. Complex echoes of course would have a profound effect on other methods of measurement of layer-height, but for other frequencies and distances than those of this work the reflections may be simple, although certainly not in all cases.[4] The possibility of complexity is to be borne in mind, however. Discussion of such points, and comparison of these layer-heights with those obtained by other investigators will be postponed pending further observations, particularly on other frequencies.

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IONIZATION IN THE ATMOSPHERE OF MARS*

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Summary—*Assuming that the atmosphere at the surface of Mars consists of 1/5 oxygen and 4/5 other gases, as nitrogen, etc., the composition of the atmosphere to great heights is calculated, just as was done for the earth, from the actions of gas diffusion and gravity. The electron density in the atmosphere of Mars due to the ultraviolet light of the sun is found to have a maximum value of* 1.1×10^5 *at a height of 440 km above the surface on a summer day, and* 0.55×10^5 *at 310 km on a winter day. On a summer day the skip distances for 100, 80, 60 and 50-meter waves are 0, 730, 1410 and 2240 km, respectively, and the shortest wave for reliable long distance wireless communication over the surface of Mars is about 47 meters. Winter and night values of these quantities are greater. Because of the skip distances for waves below 100 meters, it would seem that conditions on Mars are not very advantageous for short-wave communication, and it may be conjectured that no wireless apparatus exists there for waves below 100 meters. Waves longer than about 100 meters will not pierce through the atmosphere of the earth. These calculations, apart from other considerations, support the conclusion that only a very optimistic experimenter would look for successful wireless communication between the earth and Mars.*

IN a recent paper[1] the ionization in the atmosphere of the earth was calculated on the assumption that the ionization was caused by the ultraviolet light of the sun. Since, among other things, the solar ultraviolet energy and the action of ultraviolet light upon the atmospheric gases were not completely known, an exact calculation was not possible. What was done was to show that the sunlight falling perpendicularly on the atmosphere might be expected to produce 2×10^8 ion pairs, i.e., electrons and positive ions, in the high atmosphere each second in a 1 cm^2 column and that this rate of production gave rise to an ionization in the Kennelly-Heaviside layer in agreement with that inferred from the facts of wireless telegraphy. In the present paper a similar calculation has been made of the ionization in the atmosphere of Mars, and this has led to some rough estimates about wireless wave propagation on Mars.

Gravity at the surface of Mars is $0.38\times980=372$ cm sec^{-2}, and therefore Mars could retain an atmosphere of oxygen, nitrogen, water

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[1] Hulburt, *Phys. Rev.*, 31, 1018; 1928.
[2] Russell, Dugan, and Stewart, "Astronomy," Vol. 1, 341; 1926.

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vapor, and heavier gases, but probably not hydrogen and helium.[2] Water vapor and oxygen are detected spectroscopically in the atmosphere of Mars, but the presence of other gases as nitrogen, carbon dioxide, etc., can only be guessed. The pressure of the atmosphere at the surface of Mars appears to be roughly from 0.1 to 0.5 of that at the surface of the earth; we shall take the value 0.3. We shall assume that the atmosphere at the surface of Mars, like that of the earth, contains about 1/5 part oxygen, the rest being nitrogen and other gases. Since the total molecular density of the earth's atmosphere at sea level and at 0 deg. C is 2.56×10^{19}, the total number n_0 of molecules at the surface of Mars is $0.3\times2.56\times10^{19}=7.7\times10^{18}$ and of oxygen molecules n_0' is 1.5×10^{18}.

Assuming isothermal gravity equilibrium[3] the molecular density n at any height z cm above the surface is approximately

$$n=n_0\, e^{-pz}, \tag{1}$$

where $p=mg/kT$. g is the acceleration of gravity at the surface of Mars, m the mass of the average molecule, k the molecular gas constant, and T the temperature of the atmosphere. With $g=372$ cm sec^{-2}, $m=4.8\times10^{-20}$ grams, $k=1.372\times10^{-16}$ erg deg^{-1} and $T=300°$ Kelvin, p is 4.35×10^{-7}. With this value of p and with $n_0=7.7\times10^{18}$ formula (1) is assumed to give the total molecular density of the Martian atmosphere to great heights for a summer day, i.e., the sun directly overhead. The period of rotation of Mars on his axis is 24.6 hours and the axis is tilted at an angle of 25.2 deg. to the plane of the ecliptic. These quantities are much the same as those for the earth and therefore we assume that the Martian diurnal and seasonal temperature changes and wind currents are roughly similar to those of the earth. Maris[4] has discussed the wind currents in the high atmosphere of the earth, and has shown that they will keep the various gases thoroughly mixed up to a level known as the "diffusion level," which is at about 160 km for a summer day; at this level n is of the order of 10^{11}. The diffusion level is lower in winter and at night. Above the diffusion level the various gases separate out under the action of gravity, their densities being given by the gravity equilibrium equation (1), the lighter gases floating above the heavier ones. The diffusion level is of course not sharply marked, the transition from the region of complete mixing to the region of gravitational separation being a gradual one. In the atmosphere of Mars n is of the order of 10^{11} at 400 km and therefore 400 km is taken to be roughly the diffusion level.

[3] Jeans "Dynamical Theory of Gases," page 309, 1904.
[4] Maris, *Terr. Mag. and Atmos. Elec.*, 33, 233; 1928

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Accordingly, the density n' of the oxygen molecules is $n/5$ for heights up to 400 km; above 400 km n' is given by $n' = n_1' \exp. [-p'(z-400)]$, where n_1' is 4.16×10^{10} the value of n' at 400 km, and p' is 4.80×10^{-7}, the value of p for the oxygen molecule.

We may now use exactly the same physics and methods to calculate the ionization in the atmosphere of Mars as were used in the case of the earth. Namely, the equation was solved which expressed the condition that in each element of volume of the atmosphere the rate of supply of the electrons and ions was equal to the rate of loss, the loss being due to three causes, (a) the diffusion of the electrons and ions, (b) the recombination of the electrons with positive ions, and (c) the attachment of the electrons to neutral oxygen molecules thereby to form negative oxygen ions. The equation and the methods of solution were exactly as described in (18) and pages 1027 to 1029 of reference 1, and there is no need to give further details here. Since the distances from

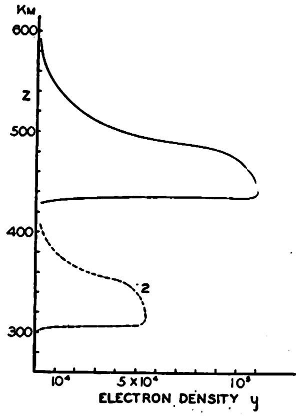

Fig. 1—Calculated electron density curves for the atmosphere of Mars; curve 1, summer day; curve 2, winter day.

the sun to Mars and to the earth are 227.7×10^6 and 149×10^6 km, respectively, the rate of production q of electrons per second in a 1 cm^2 column of the atmosphere of Mars is $2 \times 10^8 \div (227.7/149.5)^2 = 8.6 \times 10^7$; q for the earth is 2×10^8. The values of the recombination and the oxygen attachment coefficients were the same as those worked out for the case of the earth. The electron density, given in curve 1, Fig. 1, was found to have a maximum value of 1.1×10^5 at a height of 440 km for the conditions of a summer day. Following out the change from summer to winter for a temperate zone, as was done for the earth, the winter day electron density curve is given in curve 2, Fig. 1. Below their maxima the curves drop quickly to low values, and as pointed

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out for the case of the earth they probably do not represent correctly the ionization below the maxima. The ionization in this region is undoubtedly greater than that given by the curves, but in spite of this the curves serve fairly well as first approximations and are used to derive some conclusions about the propagation of wireless waves. If the atmospheric pressure, and particularly the oxygen pressure (because the oxygen attachment term is an important one in the electron density equation), is an order of magnitude greater or less than the value which has been used the electron density curves of Fig. 1 will be raised or lowered, respectively, some 50 km.

Assuming that the wireless waves are sharply reflected from the summer day electron layer of curve 1, Fig. 1, and assuming no magnetic field, the limiting wave, defined as the shortest wave which can be used for reliable long distance communication, is 47 meters; see reference 1, equation (26) for the calculation. The skip distances were calculated[5] and are given in Fig. 2. The values of the skip distances

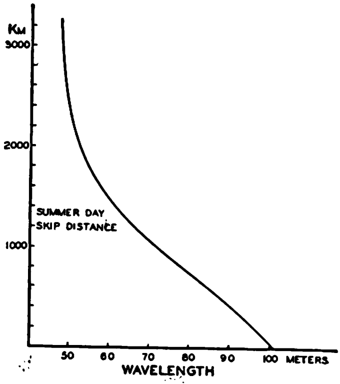

Fig. 2—Calculated skip distance curve for a summer day on Mars.

and the limiting wave thus determined may be as much as 40 per cent too large because there may be appreciable ionization below the 400-km level which has been neglected. The summer night values and the winter day and night values are greater than the summer day values. The skip distances on Mars occur for longer waves than on the earth, because the maximum density of ionization is less and is at a greater height than in the case of the earth, and because the radius of Mars is 3370 km, which is smaller than the 6370-km radius of the earth. Since the skip distances are fairly great for waves less than 50 meters, we may conjecture that commercial wireless circuits on Mars would

[5] Tavlor and Hulburt, *Phys. Rev*, **27**, 189, (1926), equation (8).

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hardly use wavelengths below 50 meters and that short-wave communication would be mainly in the 60 to 120-meter band. The advantages of long distance low-power transmission peculiar to the short waves below 30 meters on the earth are, however, not so pronounced for waves longer than 60 meters, and on the whole one might suppose that the conditions on Mars are more suited to long waves, 1,000 meters or greater, than to the short waves. These conclusions might be modified if there were a magnetic field on Mars.

The longest wave λ_1 which can penetrate through an electron layer of maximum electron density y_1 is obtained by putting $\mu=0$ and solving for λ in the expression for the refractive index $\mu=1-y\, e^2\lambda/\pi m$, where e and m are the electronic charge and mass; this is the expression for the refractive index with no magnetic field. For a summer day on Mars $y_1=1.1\times10^5$ and $\lambda_1=100$ meters. Waves longer than 100 meters will be reflected (refracted) back from the electron layer, and waves a little shorter than 100 meters, although they will pierce through the layer, will suffer considerable loss in intensity by partial reflection and possibly by absorption, the loss due to these causes decreasing with the wavelength. For summer night and for winter conditions y_1 is less than 1.1×10^5 and waves longer than 100 meters may pass through the layer; for example, on a winter day $y_1=0.55\times10^{15}$ and $\lambda_1=140$ meters. In the atmosphere of the earth on a summer day $y_1=3\times10^5$ and $\lambda_1=61$ meters; on a winter day $y_1=1.5\times10^5$ and $\lambda_1=85$ meters, and in the late hours of the night when y_1 may be as low as 8×10^4, λ_1 is 137 meters. For wireless communication between Mars and the earth one should perhaps use waves well below 100 meters in length in order to penetrate our own atmosphere. But in view of the suggested poor conditions on Mars for the utilization of these waves, it may be that there are no short-wave receiving stations on Mars, except possibly those for experimental or research purposes. The polarized wave longer than 214 meters (discussed in reference 5, equation (2), and pages 209 and 215) which might pierce our atmosphere, is of speculative utility depending as it does on the intensity of magnetization of the electron atmosphere. From the present calculations, quite apart from other considerations it is concluded that only a very optimistic experimenter would look for successful wireless communication between the earth and Mars.

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NOTES ON THE EFFECT OF SOLAR DISTURBANCES ON TRANSATLANTIC RADIO TRANSMISSION*

By
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In 1923 when the relation between abnormal long-wave radio transmission and solar disturbances was first noted, the outstanding abnormality was the great decrease in night time signal field strength accompanying storms in the earth's magnetic field. There was a slight increase in daylight signal field but this was distinctly secondary to the effect upon night field. Previous to 1927, data on signal fields were limited to one set of measurements a week, and although daylight signal field strengths were higher during periods of increased magnetic activity, it was somewhat difficult to determine the effect of individual storms. The present notes show the effects of individual storms of 60-kc transatlantic radio transmission and also give some indication as to their effect on short-wave radio transmission.

It should be borne in mind that it is not felt that disturbances in the earth's field are in themselves responsible for the abnormal radio transmission, but that these two phenomena along with earth currents, aurora, etc., result from some cause or causes, attributable to the sun. In a previous paper, radio transmission was correlated with all these phenomena. In these notes disturbances in the earth's magnetic field alone will be taken as the criterion of the solar state.

The results are in general as follows:

1. The higher daylight signal field strengths on 60 kc obtaining during periods of increased solar disturbances are associated more with general magnetic activity than with individual storms.
2. Individual storms do tend to increase 60 kc daylight signal fields, however. For the more severe storms during 1927 and 1928, the result was an increase of about 30 per cent on the day the storm began to about 75 per cent for the four or five days following. The effects of individual storms vary greatly, however.
3. The day-to-day signal fluctuations on 60 kc are much greater during periods of greater magnetic activity and are greater during the winter months than during the summer months.

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4. Magnetic disturbances are accompanied by a large decrease in short-wave signal field strength on the day of maximum activity. Even mild magnetic storms may be accompanied by a reduction of signal field to or below the measurement limit. The recovery is a matter of one to seven or eight days depending on the severity.
5. Within a narrow range, an approximate linear relation is found between daily short-wave radio field strengths expressed in decibels above or below 1*u*v per meter and the daily average of the horizontal component of earth's field.

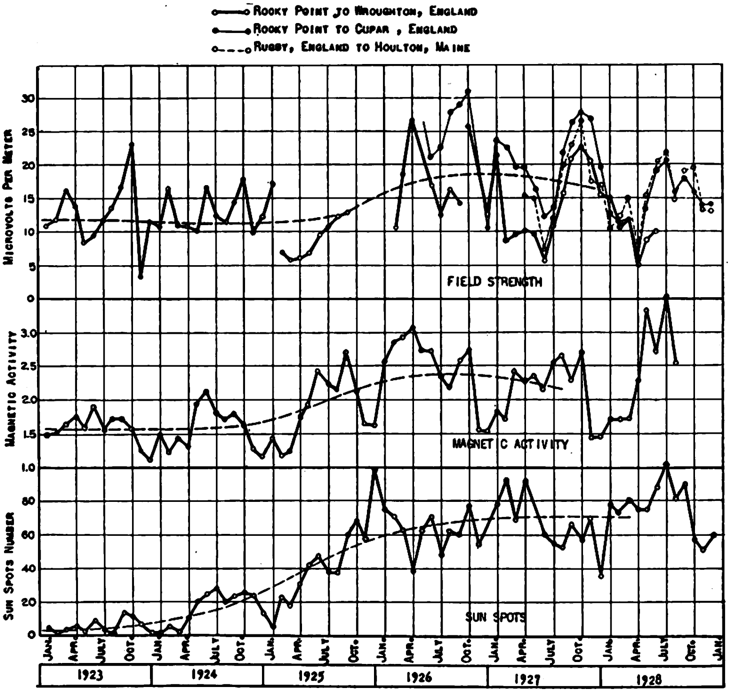

Fig. 1—Monthly average of daylight radio signal fields. Compared with monthly averages of magnetic activity and sun spots. Signal fields corrected to 5000 km distance, 3000 meter amperes, and 60 kc transmission frequency.

Effect on Long-wave (60 kc) Transmission

Fig. 1 shows the general variation in the trends of long-wave daylight radio transmission and activity of the earth's magnetism and sun spots. The increase in field strength with increase in the above activities is quite apparent. A large part of this gain in signal field is realized as a gain in signal-to-noise ratio as, in general, noise appears

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to be quite unaffected. This may be due to the fact that the transmission path of noise—chiefly from east, south and southwest—lies to a great extent outside the auroral zone.

Figs. 2 and 3 represent the variation in signal field strength for a number of days preceding and succeeding a number of individual

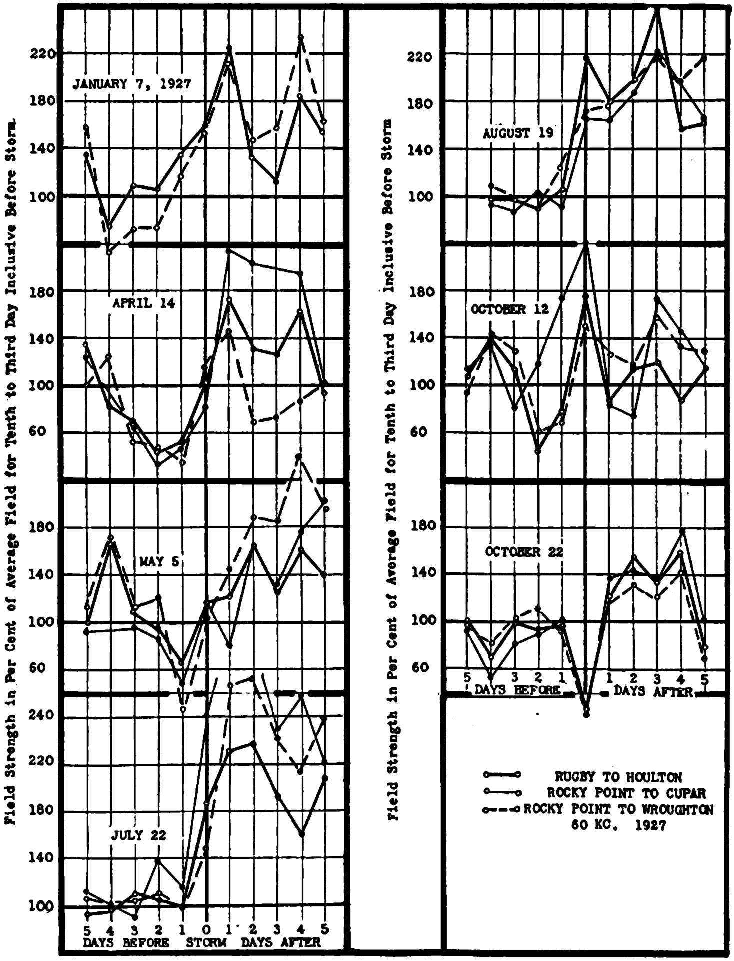

Fig. 2—Effect of solar disturbances on 60-kc daylight radio transmission.

severe disturbances in the earth's magnetic field. The day of the magnetic storm is taken as the first day that daylight signal fields could be affected after the appearance of the effect on the earth's field. For example, if the effect in the earth's field was first noted at 7 P.M., the

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first daylight fields which could be affected would be the next day; if the effect was first noted at 7 A.M., the same day was taken as the day of the storm.

It will be noted that although on the whole the effect accompanying the storms is an increase in the fields of approximately 30 per

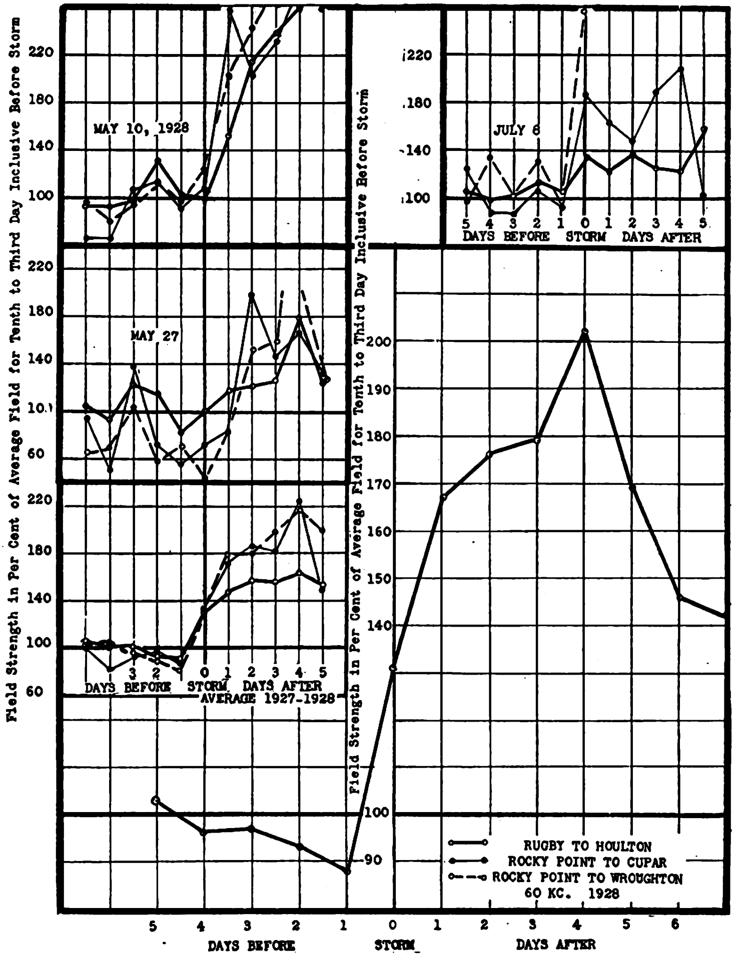

Fig. 3—Effect of solar disturbances on 60-kc daylight radio transmission.

cent on the day of the storm and 75 per cent for the four or five days following, the effect varies greatly with different storms. Although on the average curve of Fig. 3 there is a slight decrease in signal field on the few days preceding the day of maximum magnetic disturbance,

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a decided effect of this kind was noted on only one-half the individual storms. On October 22 (storm began in the earth's field at 1:30 A.M., E.S.T., October 22) the field dropped to 20 per cent of its value. In the storm beginning on October 12, 1928, the field was back to about average on the day after the storm, although it came up again on the third day. It is seen that from the first to the fourth or fifth day the fields do not follow a well defined characteristic. In the case of the storm of April 14, the results for Cupar, Wroughton, and Houlton are distinctly different.

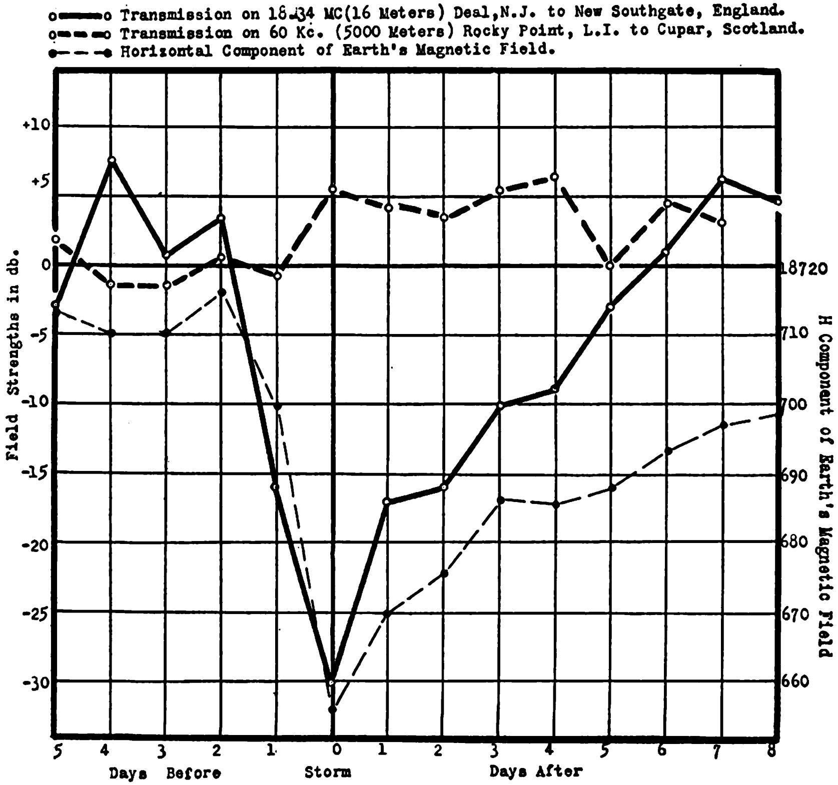

Fig. 4—Variation in radio transmission before and after solar disturbance, July 8, 1928.

The storms noted above were considered quite severe. For storms of less severity, the general effect is much less marked.

As to the significance of a 75 per cent change in field strength, it is of interest to consider the day-to-day change in field strength. For 1927 and 1928 the average day-to-day change in fields as measured

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at Houlton, was 30 per cent of the average yearly field, varying from 40 to 50 per cent in the winter time to 15 to 20 per cent in the summer. Such high percentages necessarily mean that there is considerable fluctuation in addition to that accompanying actual magnetic storms.

Daily data were not available previous to 1927 but similar figures for week-end measurements in England of transmission from Rocky Point, Long Island, give some idea of the change from year to year.

Such fluctuations consist not merely in an increase in field strength during storms and then a return to normal but also in decreases in field strengths to abnormally low values. The latter cases are most prevalent in the winter months; October to April, inclusive.

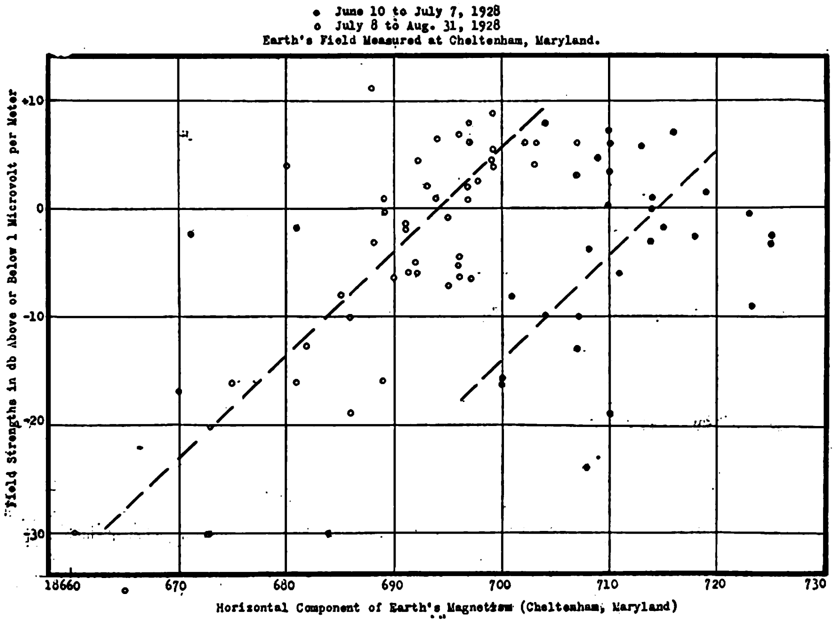

Fig. 5—Variation in field strengths with horizontal component of earth's magnetism. Transmission from Deal, N. J. to New Southgate, England. Frequency 18.34 megacycles (16 meters).

Year	Average Fluctuation / Average Field	Average Fluctuation / Average Monthly Field (Summer)	Average Fluctuation / Average Monthly Field (Winter)
1923	27 per cent	8 per cent	50 per cent
1924	25 " "	15 " "	50 " "
1925	26 " "	10 " "	60 " "
1926	31 " "	25 " "	60 " "
1927	43 " "	30 " "	75 " "
1928	55 " "	40 " "	80 " "

In view of the fact that 1923 was near the minimum of a sunspot cycle, and 1927 and 1928 near the maximum, it is seen that transmission

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is much less stable during periods of increased solar disturbances and is not confined only to such severe cases which actually result in magnetic storms.

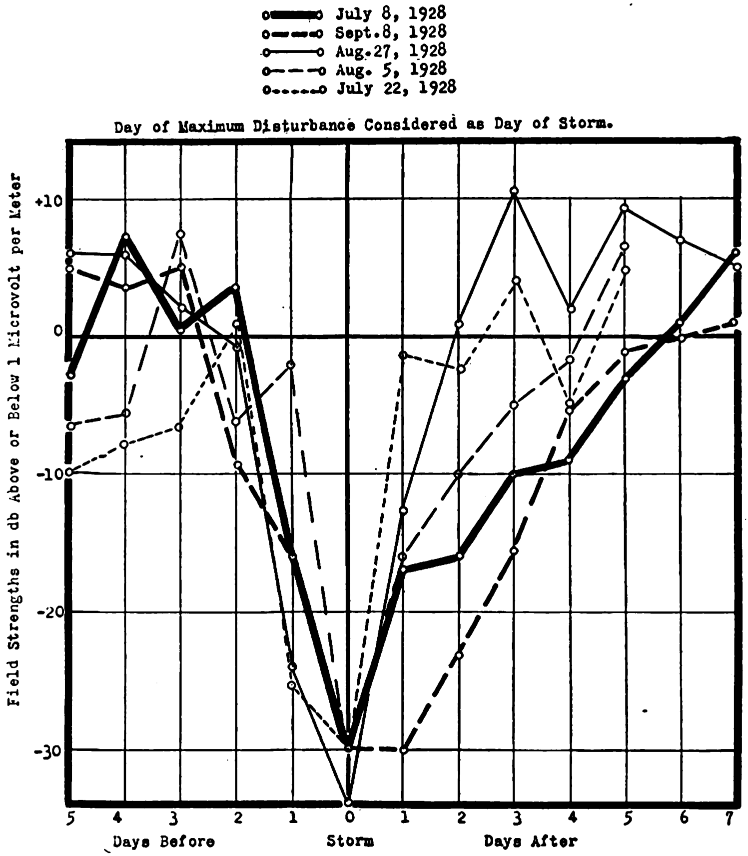

Fig. 6—Variation in field strength before and after a solar disturbance. Transmission from Deal, N. J., to New Southgate, England. 18.34 megacyles (16 meters).

Effect on Short-Wave (18.34 megacycles; 16 meters) Transmission

The effect accompanying magnetic storms in the case of short-wave radio transmission is the reduction of the field strengths almost to, or below, the measurement limits. Fig. 4 compares the effect upon long and short-wave fields for the storm July 7–10, 1928. The storm was first noticeable in the earth's magnetic field at about 2300 G.M.T. July 7, but was most active July 8, which is considered as the day of

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the storm. The long waves (60 kc) were not particularly affected before the storm began, but upon its advent the field strength increased 80 per cent and continued high for several days. At short waves (18.34 megacycles; 16 meters) the field strength went down considerably before the storm began and reached a minimum of 1/30 (or less) of normal value (30 db below 1 μv per meter) on the day the storm was most active. From then on there was a slow recovery reaching normal values some six or seven days later. In addition to low field strength, transmission during this period was subject to considerable fading signifying, as it were, unstable conditions.

In the same figure is plotted the variation of the daily average of the horizontal component of the earth's magnetic field. The agreement with the 16-meter fields suggests a possible relationship.

Fig. 5 shows radio fields plotted as a function of the daily average of the horizontal component of the earth's magnetic field from the first part of June, 1928, to the end of August, 1928. Taking all the points as a whole there does not appear to be any significant relation. In plotting the data, however, it was noted that the data points fell quite definitely into two groups, one before the magnetic storm of July 8 and one after. Within each of these groups, the distribution of the points suggests the possibility of some relation such as indicated by the dotted lines.

Fig. 6 shows short-wave radio transmission during periods of several magnetic storms in the summer of 1928. In general the decrease in fields preceding the day of maximum activity is about the same for all storms. The recovery is, however, much more rapid for the less severe storms. Of the storms in question only one was really severe and one—that of July 22—was hardly severe enough to be called a storm.

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IMAGE TRANSMISSION BY RADIO WAVES*

By

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THE purpose of this paper is to introduce a series of papers in which are described specific methods whereby transmission by radio of stationary images or moving pictures can be effectively carried out. Accordingly it has seemed desirable to establish the position of image transmission by radio in the general engineering technique of this field rather than to discuss individual methods or specialized apparatus.

All radio engineers are well acquainted with the transmission of intelligence by modulated radio waves. The simplest mode of modulation corresponds to telegraphy and is generally carried on at slow or moderate speeds and with one hundred per cent modulation. More elaborate and difficult to both the transmitter and receiver, and more critical in its electrical requirements on the intervening medium, is the transmission of speech or music, which involves modulation at higher frequencies than are generally required for telegraphy, and which similarly aims at complete modulation at peaks of sound amplitude, though with a comparatively small *average* modulation. Stationary image transmission at speeds now regarded as normal falls between ordinary telegraphy and telephone transmission in its general difficulty and physical characteristics. On the other hand, television, or the transmission of moving pictures, is by far the most difficult method of radio transmission so far seriously proposed or accomplished. The modulation frequencies are considerably higher than are required for the transmission of speech or music, the average modulation is low, but complete modulation is also desired for peaks of light or shade. Television therefore requires powerful transmitters having long and linear modulation characteristics, both as regards frequency and amplitude, receivers having similar radio and intermediate frequency characteristics indicating accurate proportionality of response, and a high quality radio circuit between transmitter and receiver. By "high quality" is meant a circuit essentially free from fading or any form of selective absorption of the radio wave.

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1. Comparison of Facsimile Transmission and Telegraph Transmission

Facsimile transmission is the transmission of stationary images. Its purpose in general is to avoid the human or variable element in transmission and reception and to enable the transmission of material which is not of simple alphabetic nature as, for example, drawings, writing or the like. It is not in itself the most rapid method for the transmission of intelligence. Certain of the five-element letter codes used in ordinary telegraphy are considerably the superior of facsimile transmission in this regard. They lack, however, the capability of carrying with any facility the special material which facsimile transmission can handle (such as pictures and the like). It is necessary to keep in mind the importance of the human element and the scope of subject matter which can be handled. In appraising the relative values of telegraphic and facsimile methods of transmission (for the same number of words per minute), facsimile transmission in general requires a more perfect circuit than does telegraphic transmission. While suitable facsimile terminal apparatus has been thoroughly developed and is amply capable of handling facsimile transmission and reception at any reasonable speed, yet radio circuits (while giving much promise of ultimate satisfactory performance for facsimile purposes), are not yet at a stage where extremely high speeds of transmission are consistently feasible over certain transmission distances or paths.

The practical conclusion is drawn that the improvement of the radio circuit, and the increasing importance of sending highly personal or graphic material without the necessity for skilled operators at each point of the circuit, will be the elements of most importance in any further study of the place of facsimile transmission in the communication field.

2. The Relation of Facsimile to Television Transmission

Television transmission is a method of communication of intelligence far transcending in its requirements any form of facsimile transmission so far developed. On the average, the transmission of an excellent facsimile picture of considerable size *at television speeds* would correspond to the transmission of a total number of dot-elements requiring but a few seconds. The actual facsimile picture sent *at facsimile speeds* may require almost as many tens of minutes for its transmission. The speed of picture element transmission is therefore in the approximate ratio of 100 to 1 or more for television as compared to facsimile transmission.

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Television is therefore found to be more susceptible to disturbance by eccentricities in the transmission path than is facsimile transmission. Extremely objectionable effects in the form of blurred or multiple images, or "explosive pictures," are obtainable under conditions when telephony or telegraphy could be carried out over the corresponding circuit with little, if any, noticeable deterioration of quality.

The limitation of the service range of television stations resulting from this feature is not generally appreciated. It is, however, a factor of importance, and it is to be anticipated that the ratio of the "service range" to the "heterodyne range" of a television station will be considerably less than for telephony, facsimile, or telegraphy. This is an unpleasant feature when contemplated in the light of future Federal assignments of television frequencies to individual stations and the repetition of such frequencies at various points in the United States. Despite considerable experimentation final data on this subject are not available.

3. The Relation of Television to Telephone Broadcasting

There are certain marked differences between television and telephone broadcasting which require consideration by the radio engineer and designer. Essentially a radio telephone signal is a single modulation of the carrier wave. A television signal, in general, will necessarily include two modulations, one corresponding to the picture, and the other (directly or indirectly) to the synchronizing means. Certain general considerations indicate that the average modulation frequencies for the picture and the modulation frequency for the synchronizing signal should not be widely dissimilar if effective and accurate framing is required. The omission of synchronizing signals implies an unusually high degree of precision in the speed controls at the transmitter and receiver and, while a possibility, does not appear at present to be the most readily available method of framing the picture, (unless occasional manual adjustment is acceptable).

As previously indicated, television requires a much wider frequency band (because of the high frequencies of modulation) than does telephony. It is accordingly more open to interference, both man-made and natural, to fading, and to selective attenuation. As a secondary result of the wide frequency band occupied, the national syndication of television programs by wire lines presents a new series of problems which, so far as one can judge from the available literature, have not yet been solved.

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Furthermore, the high modulation frequencies for television make transmitter and receiver design impracticable unless the shorter wavelengths (higher frequencies) are used for the transmission. This imposes further difficulties, namely, the considerable attenuation of the short wave, particularly in its passage over urban areas, and the generally diminished service area as compared to telephone broadcasting stations of equivalent power.

No doubt the considerations just mentioned have contributed substantially to the more leisurely progress of commercial television as compared to telephone broadcasting and have prompted caution on the part of responsible radio engineers interested in television service to the public.

4. Future Television Standardization

It is clear also that more definite and elaborate standardization will be required in the television broadcasting field than in the telephone broadcasting field. In order effectively and conveniently to receive a television transmission, the receiver must have certain constants and characteristics determined by the transmitter. It must be arranged to handle the same number of horizontal and vertical elements in the picture, the same number of pictures per second, must be arranged for the same scanning method (as to direction and mode), must follow the same antenna current versus picture light-and-shade correspondence relationship, must have the same synchronizing means, and presumably must be adapted to receive the transmitted arrangement of television and synchronizing signal in one or more frequency bands.

In other words, while a telephone broadcasting receiver will in general receive almost any sort of telephone transmission (excluding only such rarely used methods as single sideband transmission and "modulation by frequency variation"), a television broadcast receiver will receive satisfactorily only the highly individual transmissions emanating from a specific type of transmitter of definite design. The conclusion to be drawn from this state of affairs is an obvious one. Clearly the establishment of unusual constants in a television transmitting station by any organization not having a wide knowledge of the broadcasting and television fields and of the probable effect of such a choice of constants on the entire television service to the public, is prejudicial to the orderly and rapid development of the television broadcasting art.

After this brief introduction, it becomes timely to place before the membership of the Institute the individual papers dealing with various phases of image transmission by radio waves.

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THE ELECTRICAL TRANSMISSION OF PICTURES AND IMAGES*

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Summary—*The objective of this paper is a discussion of some of the important principles underlying the electrical transmission of pictures rather than a description of detailed methods by which such transmission may be effected. The subject, which includes both still pictures and television, is treated as a special form of electrical communication, differing from other forms primarily in the nature of the information conveyed.*

The necessity for reducing the information represented by a picture or scene to a form where it may be expressed as a single-valued function of time is considered. This function is used as a basis for comparing picture transmission systems with the more familiar telephone and telegraph systems, and for evaluating the amount of information carried by each. The dependence of the rate at which information is train mitted upon the frequency range occupied by the signal is shown to be of fundamental importance.

The major portion of the paper is concerned with a study of the relations between the original picture and the transmitted signal as it appears in the several parts of the system. Since the excellence of any system for the transmission of intelligence is measured by the fidelity with which it reproduces the original information, the effect upon the final picture of deviations from ideal performance on the part of each element is examined. Attention is given to the conditions governing the use of modulated waves for the particular forms of signal encountered in picture transmission. The relations between the more important transmission characteristics and the appearance of the reproduced picture are considered briefly.

On the basis of the above study a number of conclusions are reached as to the performance characteristics to be sought in the several elements to be used in picture transmission systems.

THE transmission of pictures is concerned with two general fields of application. One involves the reproduction of a single still picture in permanent form. In the other, the objective is the reproduction of a succession of images at such a rate that they appear to the eye as an uninterrupted image. Phrased in this manner it is evident that what is known as television may be considered as a particular kind of picture transmission.

For many years the processes required for the electrical transmission of pictures have been known; the comparatively recent accomplishment of such transmission is due entirely to the fact that physical means for adequately carrying out these processes have only lately become available. It is significant that the required elements have been

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developed largely through the study of other methods of electrical communication, emphasizing as it does that the electrical transmission of pictures is actually an extension of principles already well understood to an additional form of information. A review of some of the factors involved in the application of the basic methods of electrical communication in this new field calls attention to many problems of importance in its further development.

The fundamental principle underlying the telegraph, the telephone, picture transmission systems, or television is that complex electric waves, which are controlled at the sending station by the sound or the image which is to be sent, are used at the receiving station to control some devices whereby the sound or the image is reproduced. In television one does not see the person at the other end of line, nor in telephony does one hear his voice. In one case, the distant person is represented by an image produced by an optical system; in the other, his voice is represented by sounds produced by an acoustical system. The only thing which is ever transmitted over the wires or through the ether is an electric wave. In any method for communicating intelligence by means of the transmission of electric energy, three major functions are always involved. At the sending end, means must be provided for imparting to an electric wave characteristics determined by the information to be conveyed. Next, means must be provided for transmitting this electric wave without injury to these identifying characteristics. Finally, at the receiving end, means are required which, under the control of the transmitted wave, reproduce the desired information.

In the case of sound the problem is relatively simple, due to inherent similarities between acoustic waves as they exist in air, and electric waves as they exist in wires; each of these may be described in terms of a quantity which varies with respect to time. In a sound wave, the air pressure at a given point varies from instant to instant; in an electric wave the current-driving force at a given point in the conductor varies from instant to instant. It is not difficult, therefore, to devise a system in which the electric force driving the current is at each instant proportional to the pressure of the acoustic wave falling on the controlling device. This has been successfully accomplished by the familiar telephone transmitter and by the radio broadcast microphone. Similarly, any apparatus by which variations in the amplitude of an electric current cause corresponding variations in air pressure may be used at the receiving end to reproduce sounds resembling those existing at the sending end. Such means are found in the electromagnetic receiver.

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In other systems of electrical communication no such convenient analogy exists between the electric wave and the information to which it must be related. In these cases it is necessary to translate the information into the form of a time variation before it is suitable for identification with the characteristics of an electric wave. With written information this translation may be accomplished by means of the Morse code. Here each letter of the alphabet is represented by a quantity which alternates between two assigned values in a specified manner. This code may, of course, be represented as a variation in one displacement with respect to another. Our familiar script may be similarly described, but unfortunately it is not a single-valued function, and consequently cannot be directly identified with a single time variation.

It is interesting to note how the telautograph solves this part of the problem. Here a point is moved as in writing. Two communication channels are employed; one carrying information as to the time variation of horizontal displacement; the other, similar information as to vertical displacement. By causing a point at the receiving end to follow these two time variations of displacement simultaneously its motion is made to duplicate that of the moving point at the sending end. The trace of its motion is all that concerns the recipient of the information; the rate at which it moves is of interest to the communication engineer, since it furnishes him with his necessary time function. In this case, time appears temporarily as a parameter common to two related displacements.

These examples have been noted to emphasize the fundamental fact that in every electrical communication system the information to be conveyed must be put into the form of a time variation. The various types of picture-transmission system are no exception. To accomplish this necessary translation in these systems there have been devised numerous scanning and distributing devices. By means of these, information regarding the tone value of each elementary area comprising a picture or subject is transmitted over a single channel individually; the several areas being dealt with in some predetermined order and at some definite rate.

Although there are many variations possible in the arrangement of the scanning and distributing means, our present purpose will be served if our attention is confined to a representative method. Imagine a given picture divided into a series of narrow parallel strips, and these strips into small sections which may be considered as elementary areas of the picture. If the image of an illuminated aperture is formed on one of these elementary areas and then moved so as to pass along all of the

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parallel strips in turn, the light passing through the picture—or reflected from it—will at any instant be determined by the tone value of the area which happens to be covered by the image of the aperture. Inasmuch as the location of the portion of the picture selected in this manner changes from instant to instant, the intensity of the light must change correspondingly, and the desired translation from a variation which can be defined in terms of space only, to one which can be defined in terms of time, has been effected. A similar procedure may be used to effect the complementary distribution at the other end where these time variations in light intensity are duplicated by the controlled variations of some suitable light source. If this light is used to illuminate uniformly an aperture, the image of which is moved over a surface in a manner identical with that of the image at the transmitting end, the light falling on any point is thus determined by the intensity of the local source at the instant when the area is exposed. As the exposed area moves from point to point, the various tone values are distributed over the illuminated surface, and the retranslation from a variation which can be defined in terms of time only, to one which can be defined in terms of space, has been effected.

Although we have secured the desired variation in tone value with respect to position, we have not yet secured a complete image, as the variation with time has not been eliminated. It is necessary, therefore, to provide further means to enable us to combine a series of successively illuminated areas into a complete picture. If we move the image of the variably illuminated aperture over a photographically sensitized surface, the tone values corresponding to each position will be recorded. During one complete distributing operation each elementary area will be exposed, and the surface will, on development, exhibit simultaneously the desired space variations in tone value. In other words, information about each separate area has been stored up until the entire message has been completed, in order that it might be examined as a whole. If, instead of making a photographic record, we observe the light as it is directed to successive portions of the image area, we will see a complete image, provided the eye receives impressions from the last areas while those received from the first are still retained by the retina. Further, if repeated images thus formed follow each other in rapid succession, any motion of the object or image at the transmitting end will be accompanied by a corresponding change in the image at the receiving end, and the effect of motion will be obtained. Thus the apparently moving image seen in television may be thought of as made up of a succession of individual still pictures exactly as in the projection of motion pictures.

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By means of these scanning and distributing devices, and image-storing processes, it is possible to overcome the lack of a common characteristic between a visual image and an electric wave, and to express one in terms of the other quite as readily as in the case of a sound wave and an electric wave. To complete the picture transmission or television system, therefore, it is necessary simply to combine these functions with those of the three elements which we have already found to be present in every electrical communication system, namely, a device for controlling the current, an electrical transmission medium, and a device controlled by the current.

In any of the various electrical communication systems the most important part of the problem of the design of the system has to do with the amount of information which is to be carried. It is apparent that in any picture-transmission system the amount of information is related to the number of discrete elementary areas which are to be recognized. In order to reproduce an exact duplicate of the original picture it would be necessary to make infinitesimal both the width of the parallel strips into which it is divided for scanning and the elementary lengths of these strips. Since this would involve an infinite number of elementary areas, and consequently an infinite amount of information, it is necessary to examine with some care the magnitude which the individual areas may be permitted to have.

In the original picture each of the strips into which it is divided may be crossed by lines of varying tone value. If we assume that light is collected from an infinitesimal elementary length of strip, its value represents the average tone value of the element. In the reproduced picture, again assuming that the trace is made by an aperture of infinitesimal length, the individual strips are built up of cross bars of uniform tone value, all of which must lie at right angles to the strip. Each of these elementary lengths in the reproduced picture has, in the ideal case, a tone value proportional to the average tone value across the corresponding elementary length in the original picture. This failure to reproduce the actual distribution of tone value along each elementary bar results in distortion which appears as a definite structure in the picture.

If the width of a single strip is so small that the eye is unable to distinguish any change in tone value which may occur across it, the reproduced picture will appear to be as free from structure as the original. It has been found that this condition is approximated by using one hundred scanning paths across a picture one inch wide. As the strips are made narrower there is a slight improvement. With

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two hundred strips per inch the structure would rarely be detectable by ordinary inspection. If the strips are made wider, however, the deterioration in the appearance of the picture is very rapid, the structure with seventy-five lines per inch being so marked as to be objectionable. Although the nature of the structure in picture transmission is quite different from that used in the halftone printing process, there is a close correspondence between the number of structural elements per inch in the two cases for a given picture quality. The above distortion is inherent in the method used for reproducing the picture. It is fixed by the design of the apparatus and the limit to which it is reduced is set largely by economic considerations.

Our chief concern in building apparatus for the transmission of any information is the fidelity with which the system reproduces the original information. To investigate the effect on the final picture of deviations from ideal performance on the part of each of the several major functional elements, we must study in some detail the phe-

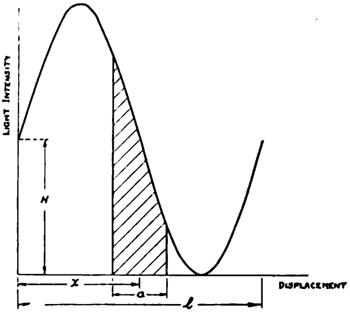

Fig. 1—Amount of light transmitted through a rectangular aperture moving along a path having a sinusoidal variation in density.

nomena which take place in transmitting information as to the variations in tone value along the several strips constituting the entire picture surface.

We have first to consider the nature of the variations in intensity as the light is collected from a small area moving along this strip. Let us take a sinusoidal variation in tone value and determine the relative amounts of the variation in light as apertures of different length are moved along it. The condition is represented in Fig. 1. The variation is drawn as taking place about an average value, such that the minimum intensity is exactly zero. The results would be unaltered if larger average values were used. Smaller average values are physically impossible. In the figure, a equals the aperture length and l equals the length of a cyclical variation. The average value is represented by H.

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The amount of light passing through the area defined by the aperture image is shown as the shaded portion of the figure. The expression for this area is

$$A = \int_{x-a/2}^{x+a/2} \left(H + H \sin \frac{2\pi x}{l} \right) dx$$
$$= Ha + \frac{lH}{\pi} \left(\sin \frac{\pi a}{l} \right) \left(\sin \frac{2\pi x}{l} \right). \tag{1}$$

If the aperture length is expressed as a fraction of the length of a cycle, that is, if $a = kl$, the above expression becomes

$$A = klH + \frac{lH}{\pi} \left(\sin \frac{2\pi x}{l} \right) (\sin k\pi). \tag{2}$$

It is evident that the maximum amount of light should be obtained when the center of the aperture is at the position $x_1 = l/4$, and the minimum amount when it is at $x_2 = 3l/4$. The relations between maximum, minimum, and average value have been computed for a number of ratios of aperture length to cycle length. In Fig. 2 the ratio

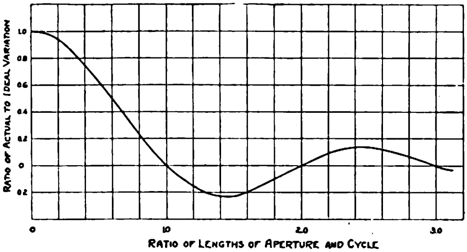

Fig. 2—Performance of an actual aperture relative to an ideal aperture as a function of the ratio of the aperture length to the length of a cyclical variation in picture density along the aperture path.

of the actual amplitude of the variation to the ideal amplitude has been plotted as a function of the ratio of these lengths. From this it is seen that when a single cyclical variation of the picture has a length equal to that of the aperture the observed variation becomes zero. Beyond this point, that is, with cycle lengths less than the length of the aperture, the variation reappears. Now, however, the variation in light intensity is exactly out of phase with the variations which would be given by an ideal aperture located at the center of the actual aperture. In other words, when the center line of the real aperture lies on the element of maximum density we receive maximum light instead of minimum light. When the cycle lengths become less than one-half the aperture length the variations again appear in their correct phase.

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It is seen from an examination of the curve given in Fig. 2 that in order to secure light variations having amplitudes reasonably proportional to those which would be obtained by an ideal aperture—that is, one of infinitesimal length—it is necessary that the length of the aperture be less than about one-third the length of the minimum cyclical variation which is to be transmitted. A complete analysis of the effect of finite aperture dimensions is contained in a previously published paper.[1]

For convenience in discussing the performance of the several functional elements of the transmission system it is desirable to express the complex variation in light intensity in terms of the frequencies of its sinusoidal components. If some cyclical variation in picture density is repeated in a length l of aperture path, and if the aperture moves a the velocity v, the frequency of the resulting cyclical variation in light intensity will be v/l. It is possible, therefore, to determine at once the frequency range of the variations which are encountered during the transmission of the picture and which, consequently, must be taken into account in the design of the system.

The first important fact is that the light intensity always has a positive value. It differs in this respect from an acoustic wave which has alternate positive and negative values. In describing in terms of its several sinusoidal variations the light obtained when a picture is scanned, we must, therefore, include a component of fixed amplitude; that is, of zero frequency. It is this component which is related to the average tone value of the picture. For example, a picture made up of alternate strips of black and dark gray exhibits changes in tone value which are identical with those obtained from a picture made up of alternate strips of light gray and white. The difference between the two pictures lies wholly in the average value of the light intensity. It is imperative, therefore, that information as to the amplitude of this zero frequency component be transmitted if we are to distinguish at the receiving end between these two pictures. Inasmuch as variations in average picture density may occur slowly throughout the entire transmission operation, it is apparent that there will be also present components of extremely low frequency.

To establish a definite upper limit to which the system must be made to respond, let us assume that each picture strip is divided into elementary lengths equal to the width of the strip. This condition approximates equivalent resolutions along the strip and at right angles to it. On this basis, the maximum frequency at which recognizable

[1] Gray, Horton, and Mathes, "The Production and Utilization of Television Signal," *Trans.* A. I. E. E., 46, 918–934, 1927; *Bell System Tech Jour.*, October, 1927.

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variations occur is $v/2d$, where d is the assigned elementary length. If n is the number of picture elements per unit area and A is the area transmitted per second, this limiting frequency may be expressed as $nA/2$ cycles per second. On the basis of 10,000-unit areas per square inch we must have, if this area is to be transmitted in one second, a frequency range extending from 0 to 5,000 cycles per second.

In picture transmission it is possible to choose the rate of transmission to fit the frequency range of the available communication channel. In television, however, the time allotted to a single scanning operation is fixed by the necessity of completing the operation in a time less than that required for the image to pass from the retina of the eye. It is not the intention to recommend here a desirable value to adopt for this scanning interval. For our present discussion we may use the convenient value of twenty scanning cycles per second. Working backward, therefore, from the frequency range of the communication channel we may find, by assuming a frequency range of 20,000 cycles per second which is near the upper limit obtainable on available wire circuits and also over present day radio channels, that it is possible to transmit information regarding approximately 40,000-unit areas per second. On the basis of twenty pictures per second, therefore, the original image may be divided into 2,000 elementary areas. This division may be accomplished by crossing the image with approximately forty-five parallel paths. The number 48 is being extensively used because of convenience, since it is commensurate with the graduations on the dividing heads used in laying out the scanning disks.

The preceding considerations apply to a particular example of a fundamental proposition of communication engineering which states that the amount of information to be transmitted fixes the product of the frequency range employed by the time required.[2] For our purpose it is perhaps more convenient to say that the frequency range occupied by a signal is directly proportional to the rate at which information is to be transmitted. In the case of picture transmission the number of elementary areas serves as a measure of the amount of information.

Since it is possible to express various forms of information in common terms, namely, those of time variations, it is interesting to compare the amounts of information involved in several methods of electrical communication.

In the case of telegraphy the several letters are made up of a number of units, each of which may have either of two values. Taking the

[2] R. V. L. Hartley, "Transmission of Information," *Bell System Tech. Jour.*, 535–563; July, 1928.

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dot as a fundamental unit length the dash is commonly equal to three unit lengths. The space between letters is also equal to three unit lengths, and the space between words is equal to five unit lengths. On this basis each letter, including the space between it and the succeeding letter, requires on the average ten unit lengths. If we assume an average of five letters for each word, there are in the neighborhood of fifty elementary units required for each word. Actually, it is found that in order to preserve the signal shape reasonably well it is necessary to transmit frequencies corresponding to the third and fifth harmonics of the unit frequency. This is equivalent to recognizing 250 elementary units per word.

In telephony, studies of speech and music have yielded information as to the range of frequencies involved. With speech it has been found that commercial telephone circuits give intelligible reproduction when limited to the frequency range between 250 and 3,500 cycles per second. On high-grade transmission channels used for broadcasting musical programs it is desirable that the frequency range extend from 60 cycles per second, or even lower, to somewhere in the neighborhood of 8,000 cycles per second. If we assume, as in picture transmission and television, that each cyclical variation is made up of two time units, we find that for speech each minute of time should be divided roughly into 400,000 such units. Then whenever someone speaks at the rate of, say, one hundred words a minute, he requires 4,000 of what may be called information units per word. On the basis of the many values which have been arbitrarily assumed in making the above estimates we find that one square inch of picture, containing 10,000 units, is equivalent to only two or three spoken words, or to forty words of telegraph code. It is interesting to note that a square inch at phonograph record contains about six or seven words, if spoken of the rate of one hundred words per minute.

It is, perhaps, unusual to compare the amount of information represented by a picture with the amount of information represented by a sequence of sounds. There are today, however, so many mechanical means for recording each of these that it is possible to find several common measures. Perhaps the most striking is the recently developed talking motion picture film. Here the sounds accompanying a given action may be conveniently recorded on a narrow strip along the edge of the film on which the action is recorded. In this case the scene requires a film width of 7/8 of an inch; the accompanying sound is allotted a width of 1/8 of an inch. It therefore appears that in this system the information delivered by the loud speaker is only about one-seventh that shown on the screen. Actually, due again to the finite

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dimensions of the aperture used in recording the sound, its record is less efficient in the use of space than is the visual record. Consequently, the relative amounts of information differ by much more than the figure obtained in this way.

A more significant comparison may be made by estimating the number of units necessary to give a very good television image of an extended scene. If the reproduced image were to be comparable with a 4 x 5 photograph seen at the usual viewing distance, we have $A = 400$ and $n = 10{,}000$, on the basis of previous assumptions. The frequency range required is, therefore, 2,000,000 cycles per second wide. Admirable reproduction of any sound may be achieved by the use of a frequency range 10,000 cycles wide. Thus it appears that the ratio of the visual to the audible information received by the spectator of some event is, as an order of magnitude, somewhere in the region of 200 to 1. This figure should be kept in mind when talking of adding a television screen to your house telephone, as it gives some idea of the increased information carrying capacity which would be demanded of the nation's wire plant.

It should be emphasized that in making the preceding estimates, as throughout this entire discussion, it is the intention to point out relative magnitudes and not to recommend or to attempt to establish desirable operating values. In television particularly, no number can be fixed as representing a required amount of information; a recognizable image may be secured by ten pictures per second, each having less than 1,000 elements; twenty pictures per second, each containing 500,000 elements is probably nearer the performance expected by the eager public. Somewhere between these widely separated limits is the region in which subsequent activity will be concentrated. It will be interesting to watch the boundaries of this territory expand.

Returning now to the behavior of our physical system, the effect of the aperture may be examined in terms of the sinusoidal components making up the complex variation in light intensity. As an aperture of fixed length is moved at some given velocity v, the frequency of any cyclical variation, as we have already seen, is v/l where l is its length. Referring to the curve of Fig. 2, we have data showing the extent to which any variation is reduced by the aperture in terms of k, the ratio between aperture length and the length in which the variation completes one cycle. This suppression may be referred to the frequency at which sinusoidal variations in light intensity occur by writing the frequency as $f = kv/a = kf_o$ where f_o is the frequency of that variation which is completely eliminated. To obtain an idea of the practical significance of this relation it has been replotted, in Fig. 3, as the equiv-

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alent attenuation of the aperture, in decibels, for an aperture length equal to 1/75,000 the distance scanned in one second. The frequency scale has been laid off logarithmically.

The preceding computations of aperture performance have all been made in terms of a rectangular aperture, the image of which completely covers a length *a* of the scanning path. In general a circular aperture exhibits similar characteristics. It should be noted, however, that the variations in light through a circular aperture are not independent of the distribution across the scanning path; this follows from the fact that a circular aperture may be considered as a group of elementary apertures of varying length. The response of each element obviously depends upon the variations encountered in its own particular path, hence the integrated response depends upon the actual arrangement of tone values in the scanning path, instead of solely upon the average value of each infinitesimal length. For practical purpose, however, these differences between circular and rectangular apertures are of secondary importance as compared with the general aperture effect.

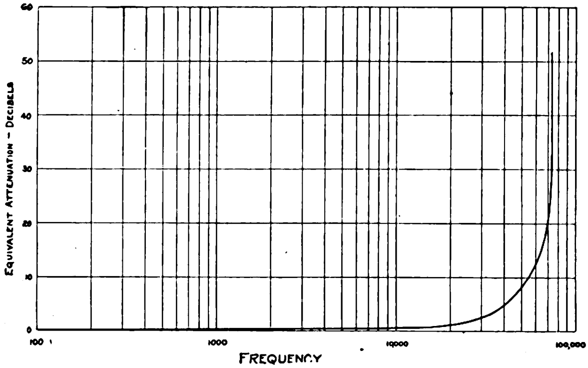

Fig. 3—Discrimination of an aperture having a length equal to 1/75,000 the length of scanning path covered in one second, plotted as equivalent attenuation against the frequency at which cyclical variations in picture density are traversed.

From the curve of Fig. 3 it appears that the aperture introduces a frequency characteristic not unlike those of filter networks or similar structures. This suggests that the distortion thus produced may be compensated for, to a certain extent, by introducing a correcting network, or equalizer, into the electrical part of the system. This has been shown to be practical in tests made by the Bell Laboratories in which cyclical variations completed in less than twice the aperture length were reproduced with negligible injury due to the aperture effect.

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The distortions already considered have to do with the method of reconstructing the picture and with the method of translating from space variations to time variations. It should be noted here that the effect of finite aperture dimensions appears both at the transmitting and at the receiving terminals where the above translations are necessary. The remaining elements of the system are concerned with transmitting information concerning the time variations in light secured by these translating methods. The effect of distortion occurring in this process must, however, be expressed in terms of the reproduced picture, rather than in terms of the variations in light intensity obtained at the receiving station.

It must be noted that any given signal distortion is significant only when the particular method of reconstructing the image at the receiving station is taken into account. This point is emphasized particularly by the method of transmission developed by the Radio Corporation of America in which the type of picture structure was chosen with a view towards minimizing the effect of static interference.[3] In other words, this system was deliberately designed on the basis of knowledge as to the distortion which must be encountered, and is directed at making the effect of a given distortion small, rather than at the actual reduction of the distortion itself.

Because of this intimate relation between signal distortion and its effect, it is not possible to undertake a purely general discussion of the requirements which must be imposed on the transmission system. The conditions in many picture transmission systems, and in practically all television systems do, however, approximate those used as the basis for our study of the scanning operation. Consequently, this general method may be retained as the basis for our study of the transmission system.

The first element of the transmission channel is that in which the amplitude of an electric current is controlled by the intensity of the varying luminous signal. The most usual means now employed for this purpose is the photo-electric cell. This contains two electrodes between which, with a suitable maintained potential difference, a current flows with an intensity directly proportional to the amount of light reaching the cell. Since this current is ordinarily very small, it is necessary to provide considerable amplification in order to obtain a wave suitable for transmission to any distance, or for the control of the illumination at the receiving terminal. Inasmuch as the average value of the signal intensity is quite as important as its varia-

[3] Richard H. Ranger, "Transmission and Reception of Photo-Radiograms," Proc. I. R. E., 14, 161–180; April, 1926.

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tions, a direct solution of this part of the problem would require what is known as a direct-current amplifier; that is, an amplifier, the output of which is strictly proportional to the absolute value of the impressed potential. Such amplifiers are notoriously difficult to build and a number of expedients have been devised for avoiding them. In some cases a few stages of direct-current amplification have been employed, whereby the signal has been built up to an amplitude such that it may be used for modulating a carrier current. This procedure effectively relocates the signal on the frequency scale, placing it in a region where it may be more conveniently handled. This relocation is unfortunately accompanied by a doubling in the extent of the frequency range occupied by the signal. An alternative method introduces the modulation into the original light source. This can be accomplished by means of a vibrating or rotating shutter interrupting the light at a frequency corresponding to that of the carrier wave.

In the photo-electric cell circuit itself there is, ordinarily, very little distortion encountered, particularly in the case of still picture transmission. The cells are able to follow variations occurring up to very high frequencies. The entire circuit, however, due to the shunting effect of the capacity of various portions of the circuit to ground, may be unable to respond accurately to frequencies in excess of about 50,000 cycles per second. Over the normal operating range of light intensities and within the frequency limits outlined above, it has been found that the amplitude of the controlled current is almost exactly proportional to the intensity of the illumination. This statement applies strictly to monochromatic light or to light of a fixed spectral distribution. In the transmission of black and white pictures the photo-electric cell introduces no tone value distortion. In television, however, the variation of sensitivity with the color of the received light introduces a distortion similar to that resulting from the non-uniform color sensitivity of photographic plates. Most photo-electric cells are relatively insensitive at the red end of the spectrum and, consequently, treat any portion of the image having only this color as though it were black. The effect is most noticeable with yellow; people with light hair being reported by the television system as having very dark hair. At the other end of the spectrum the photo-electric cell is relatively more sensitive than the human eye and, consequently, makes little distinction between green and white surfaces. This characteristic distortion may be demonstrated effectively by means of a yellow-back bill. At a distance the eye sees the yellow side of the bill almost as a uniform light surface; when reproduced by a television system, however, this side of the bill appears to be made up of a distinct

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pattern on a light ground. The pattern on the green side of the bill, even at a distance, appears to the eye in sharp contrast to the background, whereas the image reproduced by the television system appears as a uniform white surface.

The importance of preserving the correct relation between the average amplitude of the signal wave and the amplitude of the variations has already been noted. In high quality systems such as are used for the transmission of still pictures, means are provided for accurately transmitting information regarding the average tone value. In view of the difficulty of amplifying a signal wave of this character this requirement adds much to the complexity of the terminal equipment.

In certain cases it is possible to avoid the actual transmission of this troublesome component as part of the signal wave. Obviously these cases are those in which there are other means of knowing what the average value should be. With two-tone pictures such as manuscript copy, typewritten material or line drawings, it is sufficient to transmit information as to the points at which the tone value changes. The choice of the two values as they appear in the reproduced copy can be a matter for local adjustment at the receiving terminal.

In television the situation is somewhat different. Here, due to the fact that the transmission of a given image is repeated at a fairly high rate, it will be apparent that the low-frequency component which follows the variation in average value occurring throughout a single scanning operation is repeated once during each such operation, and consequently has a frequency identical with that of the scanning operation. Neglecting the effect of motion in the object being scanned, it follows that there are no important components between zero and this frequency. Because of this, it is possible to eliminate the direct-current component from the remainder of the signal during the first stages of amplification, provided this is done without injury to the component of scanning frequency. At the distant terminal information will be received as to all the essential variations taking place during each scanning operation. If, therefore, information can be obtained from some other source as to the proper amplitude to be given the zero frequency component, this may be supplied locally. Actually, this can be done without appreciable injury to the result. For example, if anywhere in the image appear two portions, the tone values of which are known, the bias can be supplied by adjusting until these two portions appear in their proper relation.

In the case of an object with which the receiving operator is totally unfamiliar, this end may be accomplished by arbitrarily introducing

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into the area scanned two small indicator areas, such, for example, as a black card and a white card. Actually, in the operation of a television system used for reproducing images similar to portraits, the average value can be adjusted by trial to give an acceptable reproduction. As a matter of fact, the distortion due to supplying this component incorrectly is likely to be less than the distortion due to the improper color value rendering of the photo-electric cell. A person with a ruddy complexion, for example, would normally appear to have a skin which is almost black, whereas a person with a dark olive complexion would appear as being unusually pale. To some extent this can be compensated for by the proper choice of the re-introduced zero frequency component.

The manner in which the average value is controlled at the receiving terminal naturally depends upon the apparatus employed. It may be introduced as a bias on some vacuum tube, in which case succeeding stages, if used, must be capable of reproducing the zero

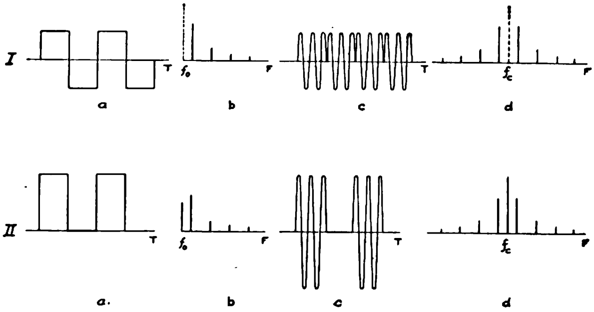

Fig. 4—Characteristic signal waves occurring in systems employing modulation.

The waves are shown as time variations. The companion charts show the frequencies and relative amplitudes of the constituent harmonic components. The original signal has no direct current component in Group I; in Group II it has no negative values.

frequency component. In practice, wherever neon lamps are used as the controlled light source the bias ordinarily required with such lamps may be made to include the bias for average value.

In picture transmission systems and in television the conditions in regard to modulation and demodulation differ materially from those found in sound transmission systems.[4] There are a number of points of particular importance which can be illustrated by the signal wave sketches in Fig. 4. The wave shown at *a* in Group I is a simple variation having alternate positive and negative values. It resembles a

[4] R. V. L. Hartley, "Carrier and Side Bands in Radio Transmission," Proc. I. R. E., 11, 34–56; February, 1923.

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sound wave in this respect and may be used to represent one in studying the phenomena occurring during modulation. At *b* are shown the frequencies and relative amplitudes of the more important sinusoidal components constituting this wave. The wave *c* illustrates the variation which would result if a high-frequency alternating current—or carrier wave—were modulated by this signal in such a way that the envelope of the final variation reproduced the original signal. Finally, at *d* are shown the components of this modulated wave.

Given only the modulated wave shown at *c* it is impossible to recover the original signal, *a*, by any known type of demodulator. The only difference between portions of the wave corresponding to positive and to negative signal values lies in their phase, and it is obvious that an ordinary rectifier would yield only a continuous current, in place of one having the desired positive and negative values. In other words, the original signal itself would be rectified during demodulation.

With the signal illustrated by Group II this is not the case. As in Group I, *a* represents the original signal, *b* its sinusoidal components, *c* the modulated carrier wave, and *d* its components. Here the original signal and, consequently, the envelope of the modulated carrier alternate between given positive amplitudes and zero. If this modulated wave is passed through a rectifier the signal will be recovered in its original form. Since the signal itself has no negative values it is apparent that it will not be altered by passing through a rectifying system.

An inspection of the two groups of components of the modulated waves shows that *d*-II differs from *d*-I only by the presence of a component, f_c, having a frequency equal to that of the carrier current first supplied to the modulator. It will be seen also that this component is related to the zero frequency component, f_0, appearing at *b*-II. Following the usual convention of looking upon every component of a modulated wave as either an upper or a lower sideband counterpart of a component in the original signal it appears that this component of carrier frequency is really the combination of the upper and lower sideband representatives of the zero frequency member. This is borne out by the fact that its amplitude is twice the value which would be necessary to maintain the correct relation with the other members of either sideband group alone.

These two signal waves demonstrate the procedure usually practiced in modulation and demodulation when sound is involved. The initial signal, with its positive and negative values, is caused to control the amplitude of the transmitted carrier wave so that the envelope will reproduce its shape but will have such absolute amplitudes as prevent

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negative values. This is done, in effect, by adding an arbitrary bias to produce a new signal similar in shape to the old, but having only positive values. Such a signal may be recovered from a modulated wave by the process of demodulation. The removal of the artificial bias restores the initial signal. The component which represents this bias in the modulated wave need not actually be transmitted over the system. It may be introduced at the receiving terminal as a carrier identical in frequency with that supplied at the transmitter. In other words, the central member of *d*-II, f_c, may be added directly, rather than as the result of having added a direct-current bias. This method is used in multiplex telephony in what are known as suppressed carrier systems. The use of the arbitrary bias in carrier and in radio telephony has caused the component of carrier frequency to be spoken of as "unmodulated" carrier. It does, however, correspond definitely to a component of the original signal exactly as do other sideband components.

In picture transmission and in television the initial signal has no negative values. Hence it is unnecessary to supply an artificial bias, or to alter its form in any way, in order to obtain a signal which may be recovered from a modulated wave by demodulation. In a modulated wave controlled by a picture signal it is clear that the component having a frequency identical with that of the carrier impressed on the modulator is a true signal component.

With certain types of demodulators it is not sufficient that the envelope of the transmitted wave remain always positive. These demodulators deliver a signal wave which approaches the shape of the envelope of the modulated wave only when the ratio between its maximum and minimum values becomes small. That is to say, these circuits function properly only with signals in which the amplitude of the variation is less than the average value of the wave. In the case of sound signals it is necessary, in order to use such a detector, merely to provide sufficient bias to satisfy the above condition. After demodulation the bias may be removed in any convenient way. In picture transmission, however, it is not permissible to alter arbitrarily the ratio between maximum and minimum signal values. If a bias—or something which may be called unmodulated carrier—is required in order to avoid distortion during demodulation, it must be removed from the signal before it can be used to control the light variations at the receiving terminal. Since the bias is equivalent to an added zero frequency component it cannot be distinguished from the signal component of zero frequency used for conveying information as to the average tone value of the picture. Consequently, its removal after

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demodulation can be effected only when information in addition to that contained in the signal wave itself is available to indicate how much of this component is bias and how much is a true signal component.

In any transmission channel, regardless of whether modulation processes are involved or not, the over-all performance may be described in terms of five operating characteristics. These describe

(1) The variation of transmission efficiency with the frequency of the impressed signal

(2) The variation of transmission efficiency with the amplitude of the impressed signal

(3) The variation of transmission efficiency with time

(4) The variation of phase shift with the frequency of the impressed signal

(5) The nature of any extraneous components which may be introduced into the signal wave, due to coupling between the channel transmitting the signal and other electrical sources.

Each of these results in introducing distortion into the reproduced picture, the nature and the magnitude of the effect being dependent upon the method used for reproduction.

We have already given some thought to the importance of various sinusoidal components to the final picture. In the transmission of still pictures similar to photographs, no deviation from uniform transmission efficiency at the low end of the frequency scale may be tolerated. At the upper end of the scale the injury which may be introduced by the transmission channel should not exceed that caused by the use of an aperture of finite dimensions. In general, the transmission efficiency should be constant from zero to a frequency equal to $v/2d$, which is the fundamental frequency resulting from passing over elementary areas of the size chosen for the picture structure. This does not permit the transmission of harmonics of this fundamental frequency. Consequently, even with an ideal aperture an abrupt change from one value to another will be distributed in the final picture over a finite length of path. In other words, the system will not permit the amplitude of the current to change with sufficient speed to form an abrupt transition from one value to the next. If the system is capable of transmitting uniformly up to the fundamental frequency occurring as the elementary areas are scanned, the change will take place in a length so short as to be negligible in comparison with other distortions. In pictures reproduced by the method on which our present discussion is based, the effect of reducing the upper limit of the transmitted range is very

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similar to the effect produced in photography when the picture is out of focus.

In television the difficulty of transmitting the zero frequency component makes it desirable, as we have already seen, to limit the lower end of the frequency range as well as the upper end. It is unavoidable that in permitting the amplifiers to reject the zero frequency component there shall be some discrimination against components of very low frequency. To obtain some idea of the distortion resulting from this let us imagine that each scanning line is constituted by a variation in tone value taking place about some average value, and that each scanning line has its own average. Information as to changes in these average values is transmitted by components having frequencies near that of the scanning operation. If these components are not transmitted at their proper value relative to other variations it follows that certain of the individual lines will be reproduced as variations about an incorrect average value.

Today it is an almost universal accomplishment to be able to listen to speech or to music reproduced by a loud speaker and to form an opinion as to the fidelity with which the low-frequency components are transmitted. There is appearing a rapidly increasing group who can, by looking at a television image, detect improper transmission of the low frequencies. One noticeable effect appears in the reproduction of images of faces. At the upper part of the picture there will probably be a clear area of background. Consequently, the first few scanning operations will result in negligible variations about an average intensity of fairly high value. As the lines pass across the upper part of the sitter's head, the light intensity alternates between that corresponding to the background and that corresponding to the hair, which is invariably reproduced as black. Consequently, the current alternates between widely different values and varies about a mean value generally less than half that of the entire picture. If the system is incapable of changing the average value quickly in passing from the upper background to the upper part of the sitter's head, it will reproduce the upper part of the background too dark, that is, with a value corresponding to the average of the picture as a whole. The upper portion of the hair will be reproduced as being of lighter color than the lower portions. Whenever an area known to be of uniform tone value, such as a background screen, is reproduced as having striations of varying darkness, it may be known at once that the system is discriminating against components having frequencies near that of the scanning cycle.

Should the system exhibit variations of transmission efficiency as

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the amplitude of the impressed signal is increased, the result will be to introduce incorrect tone values. It is probable that in picture transmission and television this non-linear distortion may exceed by a considerable amount the limits permissible in the reproduction of speech and music. In the latter case any non-linear relation between input and output amplitudes results in the production of components which were not present in the original signal. In many cases these are not harmonics of proper signal components and their presence, uneven in small amounts, is instantly detected by the ear. It is true that in picture transmission non-linear distortion results in components in addition to those belonging to the signal. Their effect, however, is rarely to alter the outline of the picture as might be at first expected. The chief result of their appearance is to reproduce a given tone value improperly. This distortion is encountered every day in photographic processes, and may exist in an appreciable amount without being objectionable. Actually, considerable non-linear amplitude distortion may be permitted even in the transmission of high-quality still pictures before the resultant injury to the picture approaches that which would be encountered in making a contact print by direct photographic processes.

The effect of any variation in transmission efficiency which occurs during the reproduction of a picture will appear as a proportional change in each tone value involved. If, during the transmission of a single still picture over wires, the attenuation of the line or the gain of some repeater were to be suddenly altered, the final picture would appear exactly like a contact print, a portion of which had been covered by a card during part of the printing process. The sensitivity of the eye to changes of this character is such that a change in transmission efficiency of the order of one or two-tenths of a decibel can be detected. If music were being reproduced a change in level of approximately one or two decibels would be needed to give a comparable disturbance. If the change occurs gradually the effect is identical with that which would be produced in photography by holding the printing light nearer one end of the printed frame than the other. A gradual drift in transmission efficiency can, therefore, be permitted provided it does not exceed something in the neighborhood of one decibel.

In television it is impossible to distinguish between variations in transmission efficiency and variations in the intensity of the light used for illuminating the scanned object. Here we have a distortion identical with a familiar phenomena, and consequently are reconciled to accepting very appreciable disturbances.

In the case of normal telephony it is known that the shape of the

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received wave differs materially from the shape of the transmitted wave. An analysis of the two, however, shows that they contain the same sinusoidal components and that the relative amplitudes of these have not been altered. The change in wave shape is due to the fact that the relative phases of the several components have been changed. It is fortunately true that the ear, to a certain extent, reacts to each of the sinusoidal components independently, and practically disregards their relative phases. In fact, in listening directly to ordinary sounds, the relative phases depend largely upon the acoustic properties of the space in which the sounds are created and heard. If the time variation in amplitude of a given sound could be photographed at a number of places in a single room it would undoubtedly be found to vary considerably from point to point. As we move about the room, however, we do not ordinarily notice marked variations in the quality of the sound, although these differences are unconsciously utilized by the ears in helping us to locate the position of the sound source. It is possible, therefore, to permit sound transmission systems to introduce a very considerable variation in the phase shift suffered by each of the components. In picture transmission, however, both the outline of the picture and the tone value of each area are dependent upon the actual shape of the received wave. Consequently, it is quite as important to retain the correct relative phases between the several components as it is to retain the correct relative amplitudes. In Fig. 5, *a* is

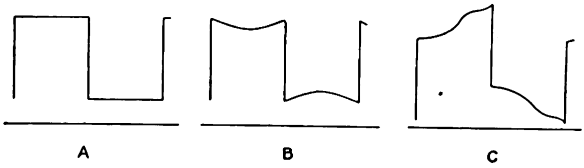

Fig. 5—Effect on a square topped wave, *A*, of distortion encountered during transmission.

At *B* the relative amplitude of the fundamental component has been reduced 20 per cent. At *C* the phase of the fundamental has been advanced 20 degrees.

a graph of the wave resulting as alternate black and white bars are scanned. The change in wave shape resulting by reducing by 20 per cent the amplitude of the fundamental relative to the remaining components is shown at *B*. The effect of shifting the phase of the fundamental by 20 degrees is indicated at *C*. In this last example the relative amplitudes of the several components are unaltered.

In the transmission of electric currents over wires the reactance encountered of necessity introduces appreciable phase shifts. If, however, the actual change in the phase of each component appearing

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at the receiving end, referred to the phase of the same component at the transmitting end, is proportional to the frequency the effect of the phase changes is equivalent to a delay in the time of arrival of the signal. In fact the ratio of the phase shift to the frequency indicates the time required for the transmission of the component. Obviously, if all components are transmitted at the same time the shape of the wave is unaltered. This requires that the characteristic relating phase shift to frequency be linear, and also that it pass through zero. In case modulation processes are involved in the transmission, the relative phases of the components in the recovered signal depend upon any alteration in phase suffered during transmission by the components making up the modulated high-frequency wave. Actually, the effective shift is equal to the difference between the phase shift of the side band component representing the original signal component and the phase shift of the component of carrier frequency.[4] Because of this, it is necessary that the relation between the phase shift and the frequency be linear throughout the region covered by the modulated wave. It is not necessary that it pass through any particular value. The frequency of the carrier stands in the position of the zero frequency components; consequently, if the characteristic is linear throughout the range, differences in phase shift between the carrier and any side band components are proportional to the difference in their frequency, and the resulting phase shift of the recovered component is proportional to its frequency.

The effect of components appearing in a signal wave used for reproducing sound as a result of coupling between the circuit carrying the wave and other electrical circuits is familiar to everybody, and is commonly spoken of as noise. It is hardly necessary to point out that the interference is actually not noise, except as it causes the acoustical reproducing system to produce noise. In picture transmission and in television, electrical interference produces flaws in the picture which may affect both the outline and the tone value. With still pictures any such flaw is permanent and a very small amount of interference is sufficient to impair seriously the quality of the reproduced picture. In television, however, the effect of electrical interference is to produce only a momentary alteration in the value of a particular point, and consequently a considerably greater amount may be tolerated. It is probable that the allowable ratio of interference to signal in television is about the same as for speech, and probably greater than for high-quality musical programs. This is certainly true for television images of the quality now possible. With improvement in other directions it

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is only natural to expect that an improvement in the matter of interference will also be desirable.

The preceding discussion may be said to have treated several of the more basic factors of picture transmission in a qualitative manner. This is true as far as the actual design of apparatus is concerned. It has been shown, however, that certain relations are inherent in the problem, and rigorously fix the operating requirements once the performance limits have been set. It is to be expected that future development of this art will result in a very considerable simplification in the means of satisfying these requirements, where the demands made on the system are more severe than those now encountered with other types of information we may have every confidence that ways will be found of meeting them.

The matter of fixing desirable performance limits is one which will have to be settled by extensive experimentation, and which will ultimately come within the scope of one form of the law of supply and demand. Picture transmission systems and television systems, like every other product of industry, will be built to those limits where the quality of the performance obtained has a value identical with the cost of securing it. Scientifically, the problems were all solved years ago; economically, it is just beginning to appear that a solution may be possible.

Acknowledgment

The information on which this paper is based was obtained while the author was in the employ of the Bell Telephone Laboratories. It is desired to acknowledge the courtesy of that organization in permitting this material to be published.

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Proceedings of the Institute of Radio Engineers
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MECHANICAL DEVELOPMENTS OF FACSIMILE EQUIPMENT*

By
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CONTINUED operation of the photoradio equipment has emphasized the value of certain modifications and developments for increasing efficiency and ease of operation. Where there are so many links in the complete chain from transmitter to receiver with all the necessary radio appurtenances to make the radio transmission of pictures and printed matter a success, the utmost simplicity of operation must be given the operator at both terminals to insure continued success of actual traffic handled.

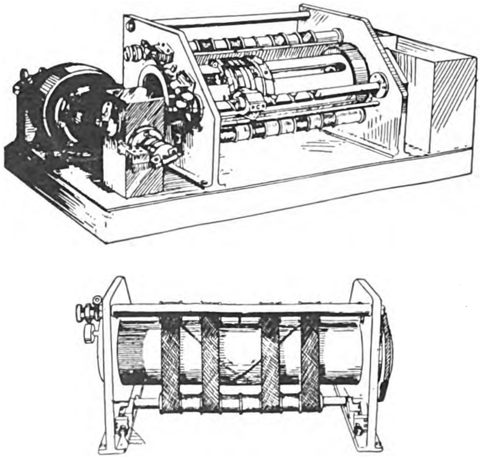

Fig. 1

In the April, 1926, issue of the Proceedings of the Institute of Radio Engineers is given a description of the first commercial equipment used for this purpose. This apparatus still continues to function well at the speeds for which it was designed. But its operation has shown where changes would be efficacious, and equipment has been evolved which not only does better what the old did, but is also able to do the transmission by a new method of transmitting across the paper in diagonal directions corresponding somewhat to the halftone line pattern of engraving.

* Dewey decimal classification: R582. Original manuscript received by the Institute, April 19, 1929. Presented before Fourth Annual Convention of the Institute, Washington, D. C., May 14, 1929.

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The first machine of this type is shown in Fig. 1. The paper is carried around a stationary half cylinder continuously from a roll. On the inside of this half cylinder is carried the head for the analyzing of the picture. At the transmitter it consists of a lens system. This head rotates and at the same time reciprocates from side to side of the sheet. The lens system is double ended with one lens 180 deg. opposite the other so that as the head rotates, one lens or the other is always actively analyzing inside the half cylinder. Around the lens is placed a doughnut light which illuminates the part of the picture being copied at each instant. Inside the head, the lens system carries back the light to the axis of the cylinder and thence axially to one end where the photocell is placed.

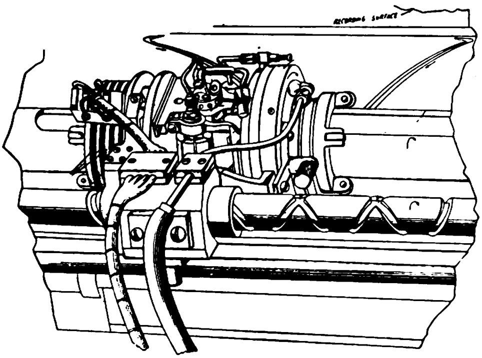

Fig. 2

The transmitter may be used as a receiver merely by substituting a neon light or similar variable light source actuated by the incoming picture signals. The doughnut light would of course not be used for reception.

In place of light recording, the hot-air recording may be used by employing a double ended hot-air gun as shown in Fig. 2.

It is seen that both transmitter and receiver work down their respective sheets of paper with a series of crossing diagonal lines in the manner shown in Fig. 3.

The value of cross diagonal transmission lies chiefly in smoothing out half-tone transmission, where the crossing of the picture in two different directions at two different times gives a smoother result and likewise covers over any omissions made on one transmission by those on the other. This is particularly useful in reducing the effect of fading when using short waves.

One of the limitations in facsimile picture transmission of printed matter is the rate at which fine lines are crossed. The speed of the

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entire system must be lowered to the point to which such crossing gives a definite marking where the picture is covered once only as by the usual method. But with the cross diagonal method, the speed may be measurably increased due to the fact that the chances are better that whereas on one crossing the parts of letters may present a very short cross-section, they may present a much broader stroke on the other diagonal stroke.

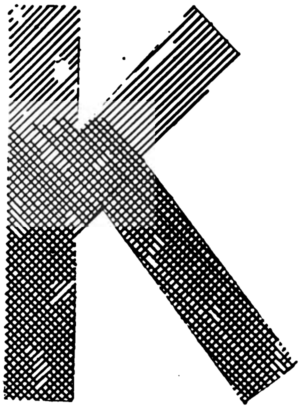

Fig. 3

A suggested result in analyzing the letter *o* is shown in Fig 4, corresponding to these conditions.

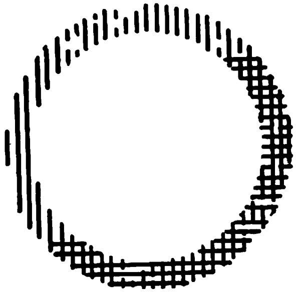

Fig. 4

A further extension of the diagonal principle is shown in Fig. 5. This equipment is capable of working either with horizontal strokes or with the diagonal strokes. The shift is accomplished by a clutch shown in Fig. 6.

As in some of our previous equipment the analyzing head is carried back and forth by means of a cross spiral thread. For straight horizontal analyzing, the head moves back and forth horizontally while

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the brass cylinder carrying the paper turns slowly upward. So that for each crossing of the analyzing head, the paper is fed forward the requisite small amount to give the next analyzing line of the picture. This of course gives a continuous paper feed.

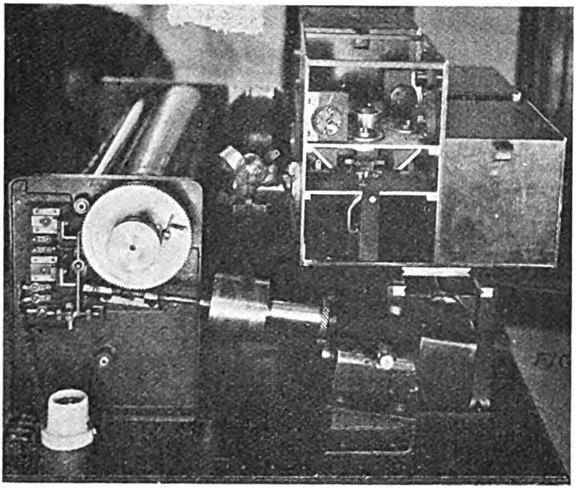

Fig. 5

To make diagonal pictures, the brass cylinder is rotated at a much faster speed; in fact it rotates just a little more than once for every complete excursion of the analyzing head back and forth. It rotates a

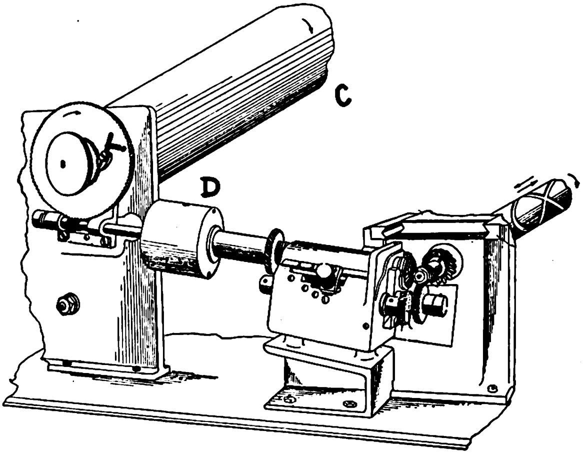

Fig. 6

little more than once in order that the diagonal line shall be just the width of a line further down on the next stroke of the analyzing head.

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To accomplish this slight increase in revolution, a rather interesting arrangement is used. As seen in the illustration of Fig. 6, the motion from the double thread is carried through a bevel gear to a differential gear in the cylindrical case *D*. If the cylindrical case were held stationary, the motion transmitted in one end of the differential would be duplicated, except for a reversal in direction at the other end. This would rotate the brass cylinder exactly in step with the double thread screw movement. But in place of keeping the differential case rigid, it is slowly rotated by other gearing so that the brass cylinder *C* is moved forward slightly more than a complete revolution for each complete action of the double thread.

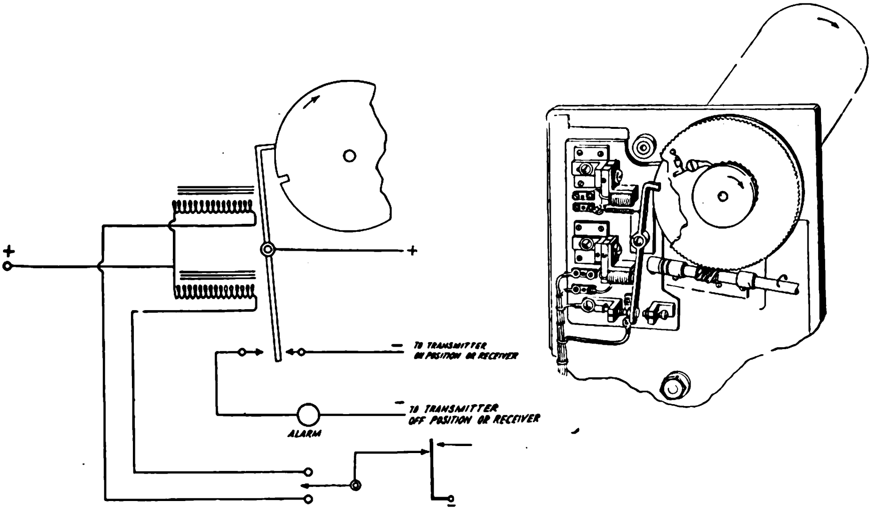

Fig. 7

Likewise a gear shift arrangement is provided on the side of this slow differential drive such that the amount of this advance may be changed at will to give different analyzing line advances, to take care of different types of matter.

There is a further modification embodied in this machine which is used on straight horizontal analyzing. This is the fact that the cylinder is made double, such that either duplicates of the same transmission may be made on the receiver, or two entirely different pictures may be made, presuming that two different pictures are placed on the transmitter. These pictures may be handled over a duplex circuit, or they may take turns about on a single circuit; the one on the left for example having the radio circuit when the analyzing heads at both transmitter and receiver are moving from right to left, and the one on the right having the circuit when the heads are moving from left to right.

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The advantage of this latter method of working is that it is then not necessary to have such accurate framing of the analysis at the receiver as is the case when the single picture is worked on both ways. In which case there must be an absolute line-up such that the points fall directly under each other on the alternate left and right strokes.

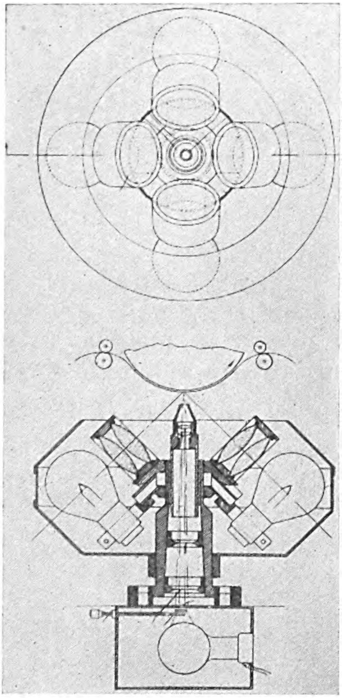

Fig. 8

A further detail is that of the automatic throwout which shuts off the transmission when the picture is completed. In Fig. 7 an arm at the left L is actuated by a contact which makes at one end of each complete movement of the analyzing head. There is one notch in the disk K in which this lever L may engage. It is started by hand from the position in which it engages. On the next stroke around, the notch will have moved forward slightly, due to the slightly faster movement of the cylinder, so that the lever arm will no longer engage. It cannot again engage until the brass cylinder has gained enough lines to carry it completely around. When it does engage the second time, it makes a contact which shuts off the transmission and gives an indication to the operator.

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The light system as shown in Fig. 8 on the transmitter is likewise unique. It consists of four lights fastened directly about the pick-up

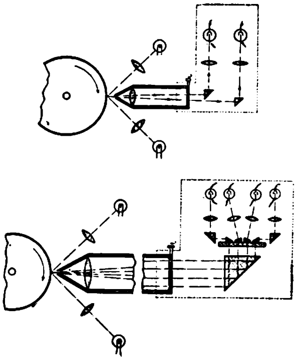

Fig. 9

lens which is to analyze the picture. Four automobile lights are used and they give a very intense illumination of the spot being traced. The pick-up lens then carries a picture of this spot back to the slit,

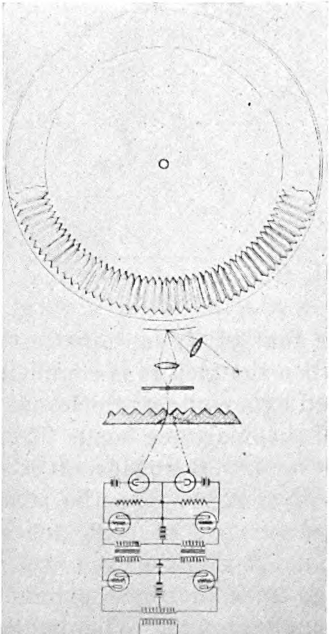

Fig. 10

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giving a more accurate definition of the exact spot being considered, and then the light is carried back to the photocell.

In place of analyzing a single point at a time, arrangements have been made to analyze as much as five points simultaneously. It is accomplished by means of splitting the light by the use of very small prisms which carry off the light of each of five different photocells as shown for four cells in Fig. 9. The purpose of this multiple scanning is looking forward to the time when it will be feasible economically

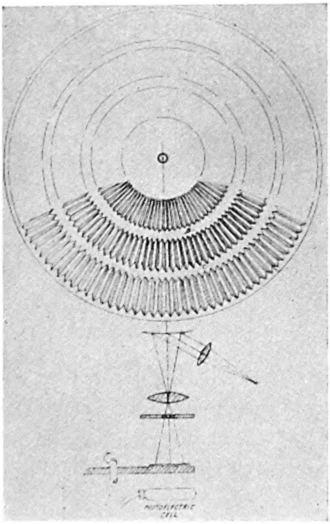

Fig. 11

to multiplex picture transmission. Then the analyzing may be speeded up by the number of channels that may be handled simultaneously.

Push-Pull Photocells

For a long time we have been aware that it was very difficult to get linear output in the complete set-up from photocell through the associated amplifiers. The natural thought is to make use of push-pull action. After many trials, I am glad to be able to report that this has now been accomplished in the rather simple form shown in Fig. 10.

It consists of the use of a glass disk on which are grouped many small prisms. The glass prisms deflect the light first in one direction and then in the other as the analyzing pencil of light comes on to first one and then the other side of these glass prisms. The deflected light is carried first to one photocell and then to the other.

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In place of driving this glass disk by the usual electric motor, which would have to be shielded most carefully to prevent it acting on the sensitive photocells and amplifiers, we have broken away completely from the electric drive and use a small air turbine. A small mechanical

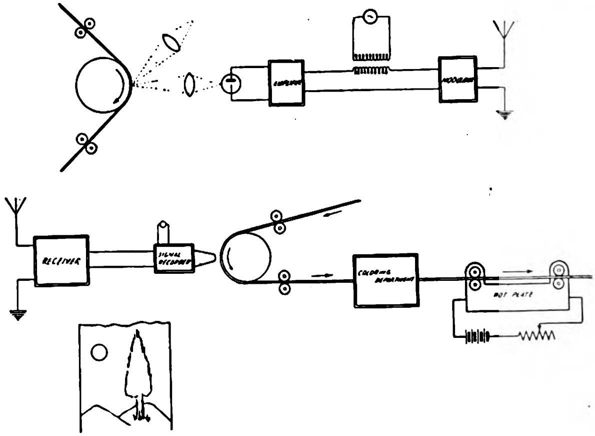

Fig. 12

governor keeps the speed within the desired scope. Two pounds of air will drive the turbine at three thousand revolutions per minute with no difficulty. This makes for a very light compact arrangement with a very small amount of vibration.

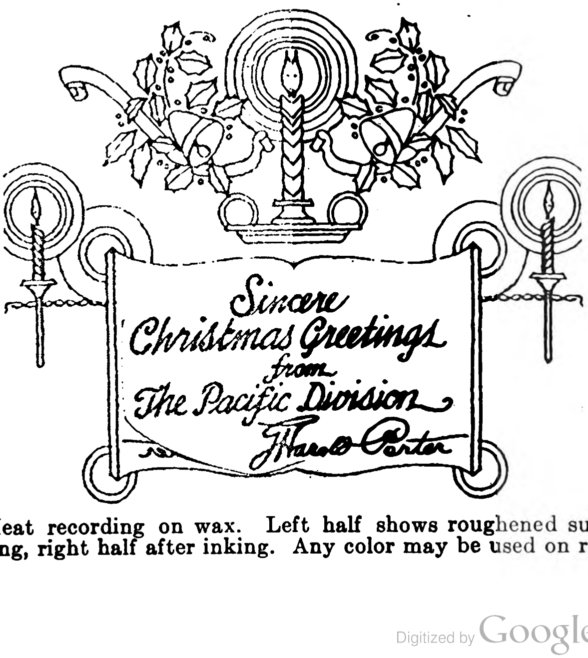

Fig. 13—Heat recording on wax. Left half shows roughened surface before inking, right half after inking. Any color may be used on roller.

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Two push-pull amplifier stages are associated directly in the camera box to pick up the voltage variations from the push-pull photocells. The resultant audio tone is then of quite sufficient proportion to be carried away from the outfit to be further amplified and put on the line to the transmitting station. In place of a single row of such glass prisms, a multiplicity of rows of such prisms has been made as

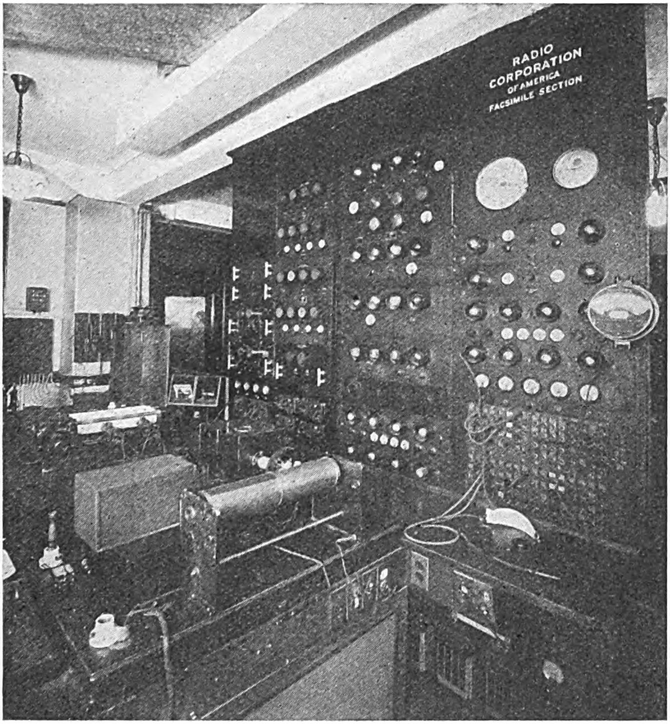

Fig. 14

shown in Fig. 11. A different number of prisms is ground in each row, and therefore different audio notes come from each row. The result is that two or more analyzing points may be picked up from the picture and separated out by appropriate tone filters later. For short distance work, the multiple tones may be carried directly out to modulate the amplitude of the radio transmitter, and be filtered apart in the final reception. It should be pointed out that without the push-pull photocell action, the wave form of each tone would be so bad that the filtering would be extremely difficult.

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It should be mentioned that the above job fell distinctly in the class of "it cannot be done," and Mr. J. N. Whitaker undertook the removal of this hoodoo most successfully as shown above.

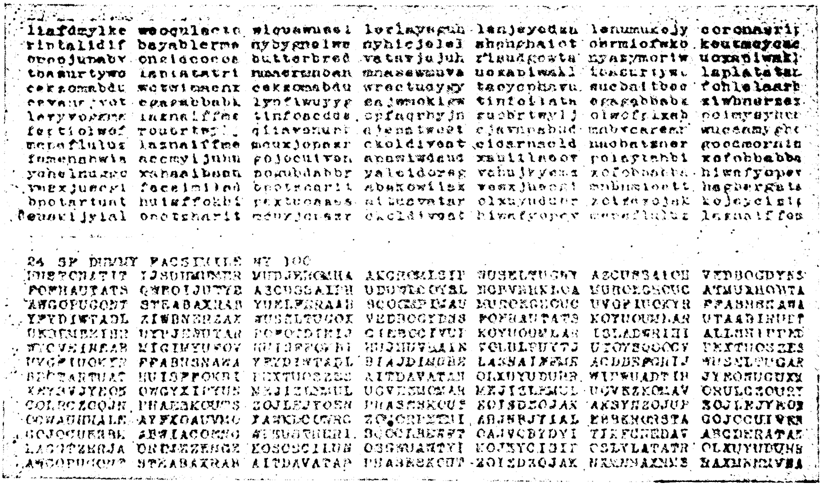

Fig. 15

TABLE OF UNITS
in
CODE AND FACSIMILE
(Average values)

1 word = 5 letters and one space

Code Transmission *(Continental Morse)*
1 word requires 24 cycles modulation
100 $\frac{\text{words}}{\text{minute}}$ requires 40 $\frac{\text{cycles}}{\text{second}}$
and therefore requires 400 cycle carrier

Facsimile Transmission
6 lines typewriting to vertical inch
12 letters or 2 words to one inch of line
12 words per square inch
1 letter requires 30 cycles modulation
1 word requires 180 cycles modulation
100 $\frac{\text{words}}{\text{minute}}$ requires 300 $\frac{\text{cycles}}{\text{second}}$
and therefore requires 3000 cycle carrier

Fig. 16

Wax Paper

At the receiving end, we are continuing the use of hot-air recording, and have now a paper developed in the hands of our chemist, Mr.

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F. G. Morehouse. It is much more sensitive to heat than the previous papers. A thin wax coating is placed on top of specially selected paper. This wax coating penetrates the paper as little as is possible. As such, the wax coating acts as a water repellent. However, when the hot-air, at a temperature in the vicinity of 80 deg. C strikes the paper from the fine nozzle, the wax diffuses into the paper and the repellent characteristic of the paper at that point is destroyed. After the transmission is finished, the wax paper is removed from the recorder, and it may then be quickly inked by a water ink from a roller.

This ink is much more permanent than our previous records, and gives a more pleasing finish to the work, as well as sharper definition.

Photo Color

Likewise in place of giving only a black record, any color may be used. And in fact the color may be applied selectively as directed by the transmitting operator. The result is a photoradio in color. This is shown schematically in Fig. 12. The first of such transmitted across the continent from San Francisco to New York is shown in Fig. 13. Unfortunately the colors cannot be reproduced here.

A general view of the amplifier equipment associated with the operations of both the transmitter and receiver is shown in Fig. 14. Some of results of recent transmission are given in Fig. 15. A synopsis of the frequencies involved in picture transmission is tabulated in Fig. 16.

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Proceedings of the Institute of Radio Engineers
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THE DRUM SCANNER IN RADIOMOVIES RECEIVERS*

By
C. Francis Jenkins
(Jenkins Laboratories, Washington, D. C.)

In the art of transmitting pictures electrically, the accepted plan is to synthesize, as well as analyze, the picture surface in a successive consideration of the several elementary areas of the surface.

For example, if the picture surface is divided into 48 horizontal lines, each of these lines is assumed to be divided into 48 elementary areas, making 2304 elementary areas for the whole picture surface.

If the complete reception of the picture takes five minutes, obviously a recording surface must be employed; for example, a photographic film or plate, an electrolytic paper, or a plain piece of paper on which ink or other coloring means is used.

However, if the speed of completing each picture is reduced to 1/15th of a second, and repeated every 15th of a second, no recording surface is needed, for, because of persistence of vision, the picture can be assembled directly on the eye, and "radiovision," "radiomovies," or television becomes an accomplished fact.

This is the method, fully described as long ago as 1884, which has been employed by all workers to the present time.

The picture scanning mechanism employed in this 1884 device and by others since, consists of a rotatable disk with 48 miniature apertures therein, the diameter of each aperture being about 1/48th the length of the scanned line, or 1/2304th part of the whole scanned area, and conveniently termed the "elementary area" of the picture surface.

As each aperture in the disk lies on its particular radius, of 48 such radii; and each aperture located approximately its diameter nearer than its neighbor to the axis of the disk, namely, in a spiral, it will readily be seen that when the disk is rotated the locus of each aperture in succession produces a linear scanning of the whole picture area.

Because this scanning disk limits the illumination to the light which can pass through a single one of these tiny holes, a powerful source of light is required for adequate lighting, just as is required in a pin-hole camera, with which it is comparable.

As such a powerful light was not available in my laboratory, I put a lens over each aperture in the disk, making the aperture as large as the working area of the lens, and a comparatively small light-source, e.g.,

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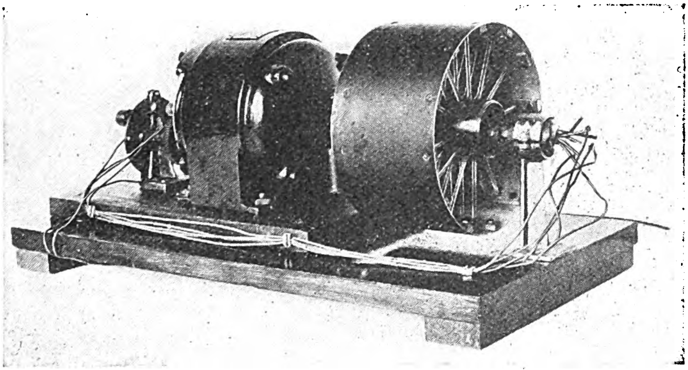
an automobile headlight lamp, was then quite adequate. The necessary elementary area was attained by focusing the light source into a pin-point on the subject or surface to be scanned.

This lens-disk was shown in some of the illustrations used with a descriptive article previously published.[1]

The same lens-disk was also used in a public demonstration of radiovision and radiomovies on June 13, 1925, broadcast from Navy Station, NOF, Anacostia, and received in my laboratory in Washington, in the presence of Navy Secretary Wilbur; Acting Secretary Judge Davis, Commerce Department; Director Dr. George M. Burgess, Bureau of Standards, and many other government officials.



The quartz rods end under the four helical turns of scanning apertures in the drum surface, and act as light channels from cathode targets.

But the disk scanner, whether apertured disk or lens disk, has physical limitations in practical application which seem, as at present employed, not to permit very much development.

In the scanning disk, the minimum separation of the apertures determines the width of the picture; and as the picture is approximately square, this aperture separation also determines the offset of the ends of the spiral.

A disk 36 in. in diameter is required, therefore, for a picture 2 in. square. A 4 in. picture would require a disk of 6 ft. in diameter—a rather impractical proposition in apparatus for home entertainment, even if it were possible to get power enough out of the house wiring to bring the disk quickly up to the proper speed.

To lay the apertures out in a multiple turn spiral does not help, for the picture size is still determined by the separation of the last two

[1] C. Francis Jenkins, *Radio News*, December, 1923.

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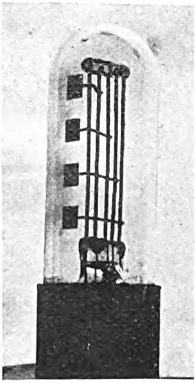
apertures nearest the axis of the disk. And such an arrangement requires a rotating mask or other complications which more than offset any theoretical advantage.

For a source of light to make up the picture in an apertured disk receiver, it is usual to provide a glowing plate cathode in a neon gas lamp.

This glowing cathode plate is looked at through the flying apertures of the rotating disk, the incoming radio signals modulating the cathode glow to build up the picture. The cathode plate for a 2 in. picture must, to provide a marginal latitude, be somewhat larger than the picture, say, 2 1/2 in. square.



The four-cathode lamp used in the hub of the drum scanner. The cathodes glow in succession.

To light this 2 1/2 in. cathode plate requires from 90 to 110 milliamperes of current, necessitating special amplification of currents obtainable from the plate of the last amplifier tube of usual radio sets.

And so the proposition as a whole does not look very enticing, and it was for these reasons that I never employed the elementary-area apertured scanning disk. The lens-disk was the nearest I ever came to it.

The drum method, however, is much more promising, for a cylinder, or drum, is free from many of the limitations of the disk, and has some very meritorious features of its own.

To get a mental picture of the drum, structurally, let us image a hollow cylinder 7 in. in diameter, 3 in. in length, and 1/16 in. wall; with a hub, hollow for the length of the drum, and about 1 1/2 in. inside diameter. The hub has an extension outside the drum which slips onto the 1/2 in. shaft of a small motor.

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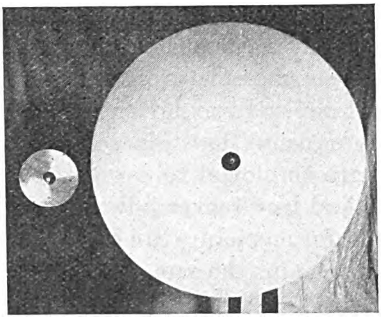
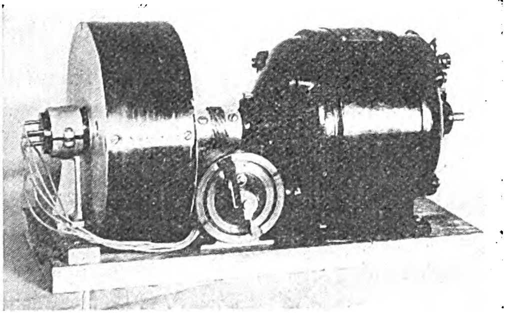
There are 48 scanning apertures punched or drilled in the peripheral wall of the drum, each aperture of elementary area, say, 1/24th in. diameter. The apertures are arranged in four helical turns and spaced 2 in. apart circumferentially, the turns being 1/2 in. apart.



The Jenkins drum (left) and the disk scanner (right) make the same size picture.

Inside the drum-hub a 4-target cathode-glow neon lamp, 1 1/8 in. in diameter, is held by a clamp mounted on the motor platform at the open end of the drum, preferably.

Between the lamp and the periphery of the drum are tiny quartz rods, each rod ending under its particular minute aperture in the drum surface.



Mechanism of drum radiovisor.

A quartz rod has a peculiar property, in that light flows through it as water flows through a pipe. That is, the use of quartz rods may be thought of as avoiding the light loss due to the inverse square law.

One of the cathode targets is located under each of the rows of quartz rods, and they are lighted in succession through a 4-segment

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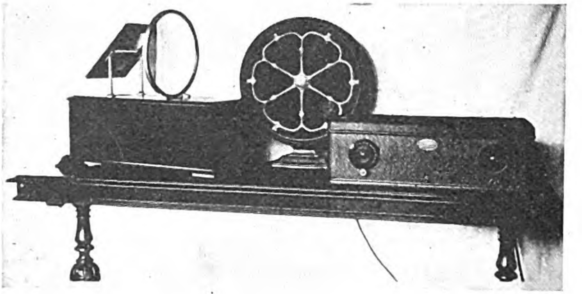
commutator, by current from the plate of the last tube of the radio receiver-amplifier.

Because the movement of the inner ends of the rods is so short, these cathode targets need be only about 1/8 by 3/16 in. in size, or, for ample latitude in setting the lamp, say, 3/16 by 1/4 in.

Such small size targets obviously require only a very small amount of current compared with the current required for the 2 1/2 in. square cathode plate of a disk scanned picture; say, 3 to 5 milliamperes. The light-modulation of these small cathode targets seems to be just as easily done, if not more easily, than a large plate.

The quartz rods are employed to avoid the light-loss due to the inverse square law. And to discover how effective they are, one has but to remove the rods, for no picture can be seen without them, though every other condition remains the same.



Showing by comparison size of radiovisor.

The miniature cathode targets lie about 3/16 in. from the inner end of the quartz rods, which at this point have relatively small movement. The size of the picture, however, is limited only by the arcuate distance from the outer end of one rod to the outer end of the next. But as the light at the outer end, that is, the picture end, of the rods is just as intense as it is within 3/16th in. of the light source itself, we get an acceptably lighted picture, for there is no loss of light in its travel along the quartz rods.

Neither does the drum scanner have another of the limitations of the disk. That is, the scanning apertures in the drum may be arranged in a plurality of helical turns without in any way changing the spacing between any of the apertures.

A drum 7 in. in diameter with scanning apertures in four helical turns gives a 2 in. picture. Magnified, the picture appears about 6 in. square; and in daily use it has been found that five or six people, the

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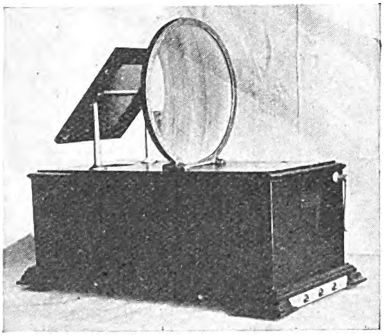
whole family, can very conveniently enjoy the story told in the moving picture.

The same size drum with six helical turns gives a 3 in. picture, unmagnified, which is more than twice the area of any picture possible with a 36 in. disk.

If the drum is increased to 10 1/2 in. diameter and turned six times per picture, the picture is 4 in. square; magnified it appears about 10 in. square; and 12 to 15 people can watch it.

The light intensity is the intensity of the tiny cathode source, which, because it is so small, requires but little current for a definite light intensity and a given size picture, the picture generated by the outer ends of the quartz rods being a virtual magnification of the light source.



The Jenkins radiovisor by which motion pictures are received in the home by radio. The picture appears in the magnifying glass to be about 6″×6″.

The light source need be but little larger than the elementary area of the picture, for the arcuate movement of the outer end of each quartz rod through which the light is flowing is comparable to the movement over the picture area of this small light source itself.

An increase in the size of the picture does not, therefore, require an increase in the light source, namely, the size of the cathode, but only a lengthening of the quartz rods; for the width of the picture is determined by the length of the arc of the angle subtended by radially-adjacent quartz rods; and the height of the picture by the number of parallel lines, each the locus of the outer end of a quartz rod from which the light emerges undimmed by its distance from the source in the hub of the drum.

The motor we most use to turn the drum is just a 60-cycle synchronous motor, for there are more homes in the a-c district of cities than in the d-c district. Even the slight frequency differences in the

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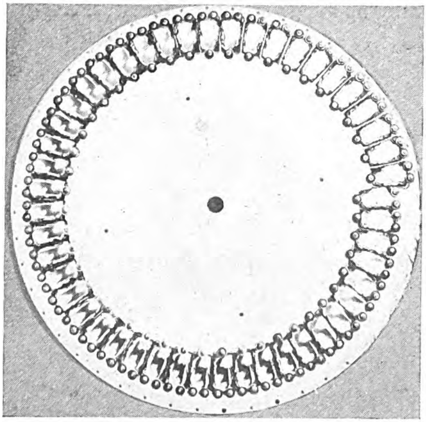
60-cycle current of separate cities often gives little trouble in the 1/15th of a second that it takes to complete each picture of the composite movie story. We have tried synchronous motor transmission and reception between Chicago and Washington successfully, and also between Washington and New York. Radiovisors for use in d.c. districts are fitted with a d.c. motor with an adjustable friction-control with quite acceptable success. Someone adjusts the drum speed as he watches the picture. If he sees a picture at all the receiver is in approximate synchronism with the transmitter; a little further adjustment makes the picture stand still. If he does not see a picture, the speed is



The Jenkins spiral lens-disk scanner.

not correct, and he turns the adjusting screw until he has a picture in frame. Synchronism in radiomovies is much more simply attained than in still pictures. We also have automatic synchronizers, but they are no part of this drum description.

Looking to the possibility of future development in this art, may I again cite for consideration the impeding fundamental in this method of picture production, namely, that each elementary area is lighted, if and when it is lighted, only 1/2304th part of the whole time.

Obviously, therefore, in the case of the single plate cathode neon lamp scanned by a disk, the current required is at least twenty-five hundred times more than it need be if it were possible to apply all the light to each elementary area in succession.

It will readily be seen that my drum method is a step in this direction. And while we have made a great gain in the multiple-target-lamp-quartz-rod combination, we are still a long way from my ideal.

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And please let me remind you also that the apparent intensity of illumination of the whole picture is the intensity of the light coming to the eye from a single elementary area, divided by the elementary time fraction, which is also equal to the number of elementary areas, namely, 2304. That is why the picture seems so dully lighted when the machine is running, though the scanning spot is very bright when the machine stops.

Multiplying this light reduction by the fractional inefficiency of the current, it will be seen that the total current-light efficiency on the eye in the scanning-disk method is less than 1/50,000th of one per cent.

Doubtless, this discouraging handicap is one of the factors which has delayed the art so long in coming into useful service.

But I am confident the solution is possible. For example, I am attacking the problem in still another way, namely, by substituting persistence of light for persistence of vision.

This new principle is incorporated in a radiomovies receiver I am now building, in which the light of each elementary area persists for an appreciable time, say, 1/10th of a second after the exciting current has passed on.

Actual tests of the fundamental mechanisms involved have convinced us that we shall have more light available than is now employed for illuminating present picture-theatre screens. And the light is white light, not neon pink; and fortunately the light source is readily available in the open market.

This same principle applied to picture transmission, namely, the substitution of persistent for transient elementary area illumination, will be an important contribution toward bringing into the home the long-promised radiovision reception of inaugural ceremonies, baseball games, flower festivals, mardi-gras, and baby parades.

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THE SELECTION OF STANDARDS FOR COMMERCIAL RADIO TELEVISION*

By

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(Research Department, Radio Corporation of America, New York, N. Y.)

Summary—*The basis of a system of television standards suitable for commercial television service, with specific standards, is discussed. The elements considered in this paper are the following: picture proportions, number of scanning elements, number of picture repetitions per second, scanning method and direction, phase of transmitted current.*

Synchronizing is considered, with possible methods, and also various arrangements for utilizing the television channel.

IT is now generally recognized that radio television and audible broadcasting differ in one extremely important respect, in that there are certain fixed elements in a television receiver which must possess constants identical with those of similar elements at the transmitting station, while in audible broadcasting receivers such a requirement does not exist. These elements are the following:

1. In the image to be reproduced, the total number of picture elements and their distribution (vertically and horizontally), together with the method of scanning.
2. The number of picture repetitions per second.
3. Phase of the transmitter modulation with respect to original object.
4. The synchronizing frequency or method to be employed for maintaining the transmitting and receiving scanning devices in synchronism.
5. The relation between the carriers of the television, synchronizing and audio signals, if both or either of the last two are radiated from the television transmitting station and all are intended to be received by a single receiver.

It is self-evident that before television can become a national service, there must be some degree of standardization of these elements among those who desire to operate television transmitting stations and those who propose to manufacture television receiving equipments. The purpose of this paper is to discuss the various factors on which the selection of standards for these elements may be based,

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and to discuss certain possible standards for consideration by engineers engaged in the television art.

The starting point for any discussion of this nature must be a definition of the grade of service which is to be considered. The rapid commercial development of the audible broadcasting art was made possible through the rendering of high grade entertainment and educational service to the public, by many broadcasting stations. If the television field is to develop similarly, we must choose for our standards those which will provide for a service of similarly high quality, or, as we will refer to it hereafter, a "commercial" television service.

A definition of what constitutes "commercial television" was given recently by a special committee of the National Electrical Manufacturers' Association, appointed to deal with the subject, and this is quoted below:

"Commercial television is the radio transmission and reception of visual images of moving subjects comprising a sufficient proportion of the field of view of the human eye to include large and small objects, persons and groups of persons, the reproduction of which at the receiving point is of such size and fidelity as to possess genuine educational and entertainment value and accomplished so as to give the impression of smooth motion, by an instrument requiring no special skill in operation, having simple means of locating the received image, and automatic means of maintaining its framing."

The phrase "genuine entertainment and educational value" really determines the degree of picture detail or the number of picture elements. In an effort to clarify this phrase one of the writers consulted with various persons engaged in the motion picture and theatrical fields and reached the conclusion that "genuine entertainment value" would be achieved if a clear reproduction of a "semi close-up" of two persons was obtainable. (A "semi close-up" in motion picture parlance is a view of a person showing half or two thirds of the figure). It appears that the majority of dramatically interesting situations reduce to two, or at most three persons; and in motion picture practice it is customary to photograph 80 or 90 per cent of a picture in close-ups or semi close-ups. It was therefore felt that if one chose a degree of picture detail that would acceptably render two persons in a semi close-up view, one would be able to meet the entertainment requirement, at least, in the early stages of the art. At the same time, it was felt that other types of subjects, such as general views, would be rendered sufficiently well in a picture of this degree of detail, to convey a satisfactory impression.

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This point of view is necessarily a tentative one at best, and is considerably influenced by apparatus and ether channel limitations. In other words, engineers are striving for a type of service which will satisfy moderate entertainment requirements and not require channels thousands of kilocycles in width or apparatus which is as yet unknown. Fortunately, as will be shown later on, the requirements given above may be met by the use of the television channels which have been made available in the United States, each 100 kc wide, and it is believed that the present state of apparatus development is also such as to make the effective utilization of these channels a possibility.

We will now proceed to a detailed discussion of the various system elements and possible standards which may be considered for each.

The authors wish to make clear at this point that the specific standards which are discussed in the following do not in any way involve the present practice or the possible future procedure of the Radio Corporation of America. These standards are considered by the authors as a suitable basis for study by radio engineers engaged in the television art, and as available for the purpose of stimulating discussion, so that at a later date a group of operating standards may be evolved which will be acceptable to the majority of those engaged in this field.

Number of Picture Elements and Picture Proportions

It has been assumed that to possess entertainment value, a received television image must reproduce a "semi close-up" of two persons with satisfactory detail. The determination of the number of elements into which the picture is to be broken is then to be made.

The greater the fineness of detail in a television picture, the wider must be the radio channel and the more complicated or expensive the receiving amplifiers, scanning and illuminating devices. Therefore some practical compromise has to be chosen which will give sufficient detail and not result in unduly complicated or expensive equipment.

In order to determine a suitable compromise, Mr. R. A. Braden of our staff conducted a series of experiments, using conventional halftones of various degrees of fineness of detail. He first arrived at a correlation between the number of "halftone lines per inch" and the corresponding television "scanning lines." Halftones of letters and photographs were made up, and their appearance compared with the television image on a 48-line system of the same original until apparent equality of detail was obtained; from this data, other halftones were made which simulate the appearance of images on television systems having various numbers of scanning lines. Some of these are reproduced and referred to later in this paper. The conclusion reached was

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that acceptable detail would just be obtained with an approximately 60-line scanning system, and, while greater detail would naturally be obtainable with a greater number of lines, such a system would meet the "entertainment requirement." This conclusion was also in agreement with the results of early work of Dr. Frank Conrad of the Westinghouse Electric and Manufacturing Company. It will be taken for granted that for any unit square area of the picture, the horizontal and vertical detail should be equal. The vertical detail is determined by the number of scanning lines and the horizontal detail by relation between the width of the scanning spot and the width of the picture. If a round or square scanning spot is employed, without overlap of rows of lines, the horizontal and vertical detail will be about equal.

Fig. 1—Equivalent detail of 60×72 picture; semi close-up.

Fig. 2—Equivalent detail of 60×72 picture; view of single person.

Fig. 3—Equivalent detail of 48×48 picture.

In determining the *proportions* of the picture, it seems logical to consider the standards of sound motion picture film, since it is believed that transmission of sound motion picture may form a considerable part of television programs. These proportions are in the ratio of 5 to 6 (height to width).

Experiments made by Mr. Braden showed that two scanning lines per inch on a human figure will give sufficiently clear reproduction for commercial television. Thirty inches is the height which, we assume, will be scanned for a semi close-up view, hence, about 60 scanning lines are sufficient. In Figs. 1 and 2 are shown the detail with which an image 60 lines high and 72 lines wide would be reproduced. Such a picture contains 4320 picture elements. Fig. 3 shows a 48×48 picture for comparison.

We have found that the improvement in detail gained by increasing the number of scanning elements over approximately 4000 is not of material advantage, when the picture contains moving objects. This is due to the fact that in following action the eye does not appreciate detail to the fullest extent. A limit is also fixed by the channel width assigned by the Federal Radio Commission as the radio side-

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bands are determined by the number of elements and the picture repetition rate.

Picture Repetition Rate

The number of pictures to be transmitted per second is a compromise which is determined by the amount of flicker perceived at the image,[1] and the frequency band available for transmission. Although flicker will be apparent on bright television images up to 24 pictures per second, it appears more practical to use a rate not greater than 20 pictures per second. While there is some flicker observable with 20 pictures per second and, as illumination of the screen is improved it may become worse, higher rates of scanning result in what are in our opinion unduly wide radio sidebands, since the frequency band is directly proportional to the picture repetition rate. If substantially less than 20 pictures per second are scanned the flicker becomes excessively annoying, particularly so for an image projected on a screen.

The frequency band required for transmission with the values now determined will be about 90 kc if both sidebands are transmitted, which can be conveniently placed in the 100-kc bands assigned for television stations by the Federal Radio Commission.

Phase of Transmitted Picture

When light variations impressed on the transmitting photo cells are finally converted into modulating currents for the radio transmitter, the number of amplifier stages (whether even or odd) following the photocell will determine whether the picture as transmitted is a positive or a negative. Each stage of the photocell amplifier causes a reversal of phase, so that if light portions of the picture correspond to maximum current in one stage, they will correspond to minimum current in the following stage. Similarly, the amplifier feeding the light source in the receiver reverses the picture (in effect) in each stage.

It seems desirable to propose that the standard method of transmission should be for a television station to transmit a positive picture; that is, maximum amplitude of radio-frequency currents should correspond to light places on the object being transmitted and minimum amplitude to dark places. Receiving equipment should be designed to reproduce a positive image from an input of this type.

[1] Throughout this paper, the word image has been used to indicate the view which will be seen on the screen of the television receiving apparatus by the observer.

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Synchronization

In order to reconstruct correctly an image from the transmitted impulses, every element must bear the same relation to the receiving screen on which the image is projected as did the corresponding element of the original picture at the transmitter. Thus, picture repetition rate must be constant and exactly equal to the transmitter scanning repetition rate.

There are in general two methods of producing identical rates of synthesizing and analyzing. The first is to have at the receiver some local periodic source which is adjusted to synchronism with the transmitting scanner. Such a local source might be an oscillator, electrical or mechanical; or a governor controlling some non-constant device.

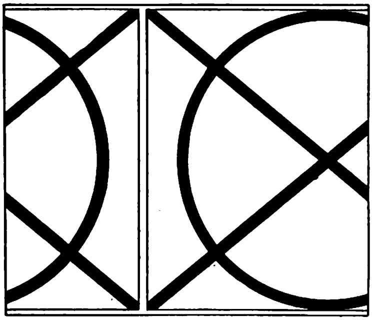

Fig. 4—Image out of frame horizontally.

In order to judge the requirements of a local synchronizer, it is well to note what accuracy is demanded of it. If, for example, 20 pictures are to be transmitted per second and about 4,000 elements per picture, then about five million impulses will be transmitted each minute. In one hour about three hundred million impulses will be sent.

Any slight change in frequency will be seen as a drifting of the picture sideways, and if the picture continues to drift it will become "out of frame" vertically. In Fig. 4 is shown an image out of frame horizontally, and in Fig. 5 one which has drifted until it is out of frame vertically.

It may be safely assumed that a drift of one-tenth of the picture width will not be troublesome, but beyond this, details of the picture may be lost. Fig. 6 shows an image one-tenth out of frame horizontally.

It is assumed that no one would wish to adjust a receiver for framing oftener than once every few minutes. A somewhat similar

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parallel would be to listen to a broadcasting receiver which continually required retuning.

If these two assumptions are adopted, then an accuracy in frequency slightly greater than one part in seven millions is required. Mr. E. S. Purington of the Hammond Research Laboratories has suggested as a parallel the corresponding accuracy of a clock, which in three months would gain or lose no more than one second. The greatest accuracy of crystal oscillators so far attained is about one part in five millions. Thus it will be seen whatever advantages local sources may possess, they are nullified by the extreme accuracy and stability which is required unless occasional framing adjustment is deemed permissible.

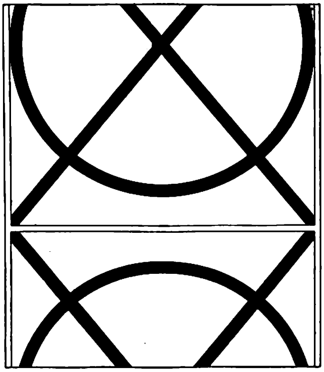

Fig. 5—Image out of frame vertically.

The other method of synchronization is by transmission of a synchronizing frequency which controls the rate of image repetition. The synthesizing rate cannot then be different from the analyzing rate; at the worst a small variation in phase may occur.

The standard of frequency which comes to mind at once is that of the electrical power supply, usually 60 cycles per second. This is undoubtedly the simplest and most widely available frequency. However, in order that the frequency at the receiver be identical with that at the transmitter, it is necessary that the power systems supplying the two be interconnected. The power system at the transmitter must therefore be interconnected with the power supply of every television receiving set to which service is rendered.

In a survey of the power distribution systems of the United States made by the General Electric Company, it was shown that while there are at least four extensive systems which tie in the power com-

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panies serving a number of large cities, there are many more which are not tied in. For example, such cities as Baltimore, Denver, Duluth, Kansas City, Minneapolis—St. Paul, New Orleans, Portland (Maine) and New York have no connections with other power systems at present. Hence they would be unable to synchronize with a station using another 60-cycle frequency. In addition many smaller cities have municipal power supplies.

In the case of New York City, while the power systems in the city are interconnected, a large part of Manhattan is supplied by direct current. There is no tie-in with either New Jersey or Long Island, and any station using Manhattan's power supply for synchronizing cannot render service to the neighboring populous districts of New Jersey, Long Island, and Connecticut.

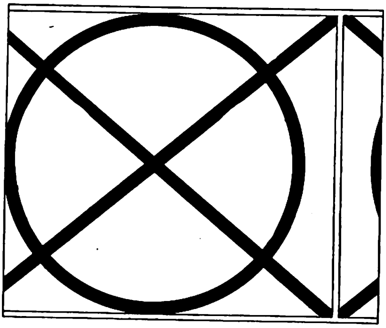

Fig. 6—Image 1/10 out of frame horizontally.

It will be obvious that until all power systems are interconnected and a uniform 60-cycle supply is universally available, no successful national synchronization can be maintained by this means. It therefore appears desirable, for the present at least, that either a synchronizing frequency be supplied by the transmitting station or occasional manual adjustment be provided.

Direction of Scanning

It appears logical to propose that scanning be arranged to proceed from left to right and from top to bottom, as observed by viewing the receiving screen, viz. Fig. 7. This is the normal method of reading a printed page and may well be adopted in television.

As regards the type of scanning, we may consider that scanning systems fall into two general classes:

1. Simple linear consecutive scanning, that is, scanning in which

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each horizontal line of the picture is traversed consecutively, as by the Nipkow spiral scanning disk.

2. More complicated or irregular scanning; for example, by means of a reciprocating device, or by the scanning of non-consecutive lines in the effort to reduce flicker.

It is likely that the simplicity of the linear scanning system will justify its adoption.

Economic Use of the Radio Channel

After the frequency and channel width shall have been decided upon for a commercial television system, the proper sub-division of the

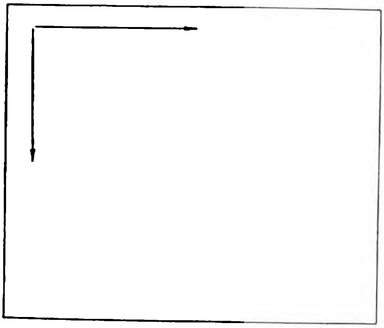

Fig. 7—Scanning direction.

available band must be made to allow for the best economic use of the frequencies in the band. At the present stage of the art, the existing regulation of 100 kc seems to be a reasonable compromise for the band width. Besides the television signal, there may be located in the band a synchronizing signal and conceivably, later on, the speech or music signal, accompanying the picture. The problem is to arrange these signals in relation to one another so as to use the whole range of frequencies provided in the most advantageous manner. This problem can only be discussed generally at the present time.

The simplest system would provide a single carrier located centrally with respect to the band. All three signals, television, speech, and synchronizing, modulate this carrier. Numerous difficulties immediately present themselves with such an arrangement. If the synchronizing signal is within the audible range, the speech would be interfered with. In addition, television frequencies would be heard and the speech frequencies would produce interfering spots and lines in the reproduced picture.

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To eliminate this cross-interference, three separate carriers may be considered, one for each of the three transmitted signals. These carriers with their respective side bands would be spaced throughout the band. Some definite separation would be necessary to allow for distinguishing the signals in the receiving set. When the characteristic selectivity of radio receiving systems is considered, it will appear that the frequency channels available for the three signals, especially the television signal, are very limited in width.

A third possible solution is to attempt to make one of the carriers serve for two signals. Again, a number of arrangements are possible. One system which has been proposed employs two carriers, the first for the speech and the second for both television and synchronizing.

A system which seems to offer some possibilities as far as eliminating cross-interference and using the available band in an advantageous manner is one which employs two carriers, the speech and synchronizing signals modulating a common carrier. It appears logical to make the carriers of equal intensity, since each carries a necessary portion of the entire signal. The speech and synchronizing signals would be incor-

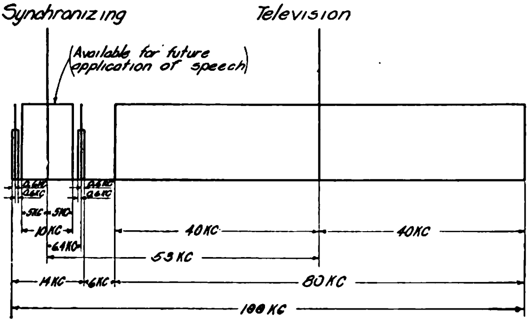

Fig. 8—Spectrum of 100-kc television band.

porated with their associated carrier so as not to interfere with one another. This might be accomplished in a number of different ways. For instance, a low-frequency synchronizing signal may be superimposed on the speech frequencies. A necessary condition is then that the intensity of the synchronizing signal be made very low compared to the speech. This arrangement has disadvantages. There is the danger of using such a strength for the synchronizing signal that it will interfere with the speech when the latter is weak. The synchronizing signal would have to be amplified to a very high degree, and, while this is no particular hardship so far as the circuits are concerned, noise and strays may easily overpower the signal. These disdadvantages do not

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apply to a system which puts the synchronizing frequency beyond the highest frequencies desired for the speech signal.

Fig. 8 shows the proposed arrangement of synchronizing and television frequencies. It will be observed that a space is left for the later addition of the speech or music signals, should this become desirable.

It will be gathered from the discussions contained in this paper that a close study of all the problems of television is essential before definite working standards can be proposed or adopted. It is hoped that radio engineers engaged in television development will study these problems and publish their views.

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NAVAL COMMUNICATIONS—RADIO WASHINGTON*

By
S. C. Hooper
(Captain, U. S. Navy, Director Naval Communications, Washington, D. C.)

Summary—*This article describes the radio facilities at Radio Washington. There is included a brief description of receiving equipment and of methods of control of transmitters in use at the Navy Department, Radio Central, and of the transmitting equipment installed at Arlington, Va., and Annapolis, Md.*

THE purpose of this article is to give a brief description of the radio installations in the Washington Communication System, and of the methods of handling radio traffic from the Navy Department Radio Central.

The office of Naval Communications, Navy Department, is a division of the office of Naval Operations. The office of Naval Communications, under the command of the Director of Naval Communications, is divided into subdivisions for the administration of the entire Naval Communication Service.

One of the subdivisions of the office of Naval Communications is the Navy Department Communication Office. This office is further divided into three sections known as the Communication Office, Radio Central, and Telegraph Office.

The first of these sections, the Navy Department Communication Office, is maintained for the proper handling and filing of messages. In this office a commissioned officer of the Navy, known as the communication watch officer, is on duty at all times to supervise the handling of message traffic.

Adjoining the Communication Office are the second and third sections, the Radio Central and the Telegraph Office, respectively, both of which are connected with the Watch Officer's desk by an endless belt automatic pick-up-and-drop system. These offices like the Communication Office are in operation continuously on a watch standing basis.

About twelve hundred messages are handled by the Navy Department Communication Office each week day, such traffic averaging over one million words per month. Of this amount approximately 75 per cent is Navy business while the remaining 25 per cent is traffic for other government departments, such as War, Treasury, Agriculture, Commerce, Interior, etc.

* Dewey decimal classification: R565. Original manuscript received by the Institute, May 16, 1929.

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However, not all of the Government traffic originating in, or destined Washington, is handled by the Navy. The Army maintains a Message Center at the War Department similar to the Navy Department Communication Office, and, in cooperation with the Navy, handles traffic to points which can be reached by the Army or Navy radio and telegraph net, or to the nearest point reached by the net for transfer to a commercial landline, cable, or radio system for ultimate delivery to the addressee. The Commerce Department, Airways Division, and the Department of Agriculture also maintain a central station for handling certain additional governmental message traffic.

With the above brief description of the Navy Department Communication Office as a whole, I will pass on to a detailed description of Radio Central—the main receiving and the control station, the monitor receiving station at Bellevue, and the two major transmitting stations—Annapolis and Arlington.

Radio Central

It will be seen in Fig. 1 that the heart of the Navy's Radio Communication System in the Washington District is at the Navy Department Radio Central. It is here that the transmitters of the Arlington, Annapolis, Washington Navy Yard, and Bellevue stations are operated by remote control, and where the actual reception and manual transmission of messages takes place.

Continuous watches are maintained for San Francisco, Balboa, Charleston, Norfolk, San Juan, Great Lakes, New Orleans, and Key West, Commander-in-Chief U. S. Fleet, Commander Scouting Fleet, and with ships of the Navy. Schedules are carried out daily with certain other flag ships and with shore stations at Rome, Rio de Janeiro, and Nicaragua. Daily broadcasts are made of messages to Shipping Board vessels and army transports, and of press, storm warnings, time signals and weather reports.

Automatic transmission by perforated tape is used in the transmission of broadcasts of weather and press, and to a limited extent for routine traffic. All weather reports and time signals are keyed from the U. S. Weather Bureau and the Naval Observatory, respectively, the transmitters being "patched" through at Radio Central.

While at present nearly all traffic is received aurally, the facilities of the office will soon be expanded to permit working high speed with San Francisco, and teletype with Norfolk.

The supervisor on duty in Radio Central may connect any transmitter by patch cord and jack arrangement to any one of the twenty-four individual operating positions. Certain additional features in the

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wiring of the control board permit him to listen in on any receiver or transmitter, or to talk to any one of the operators through their head telephones, thereby allowing him to control the entire sequence of events connected with the handling of any dispatch without leaving

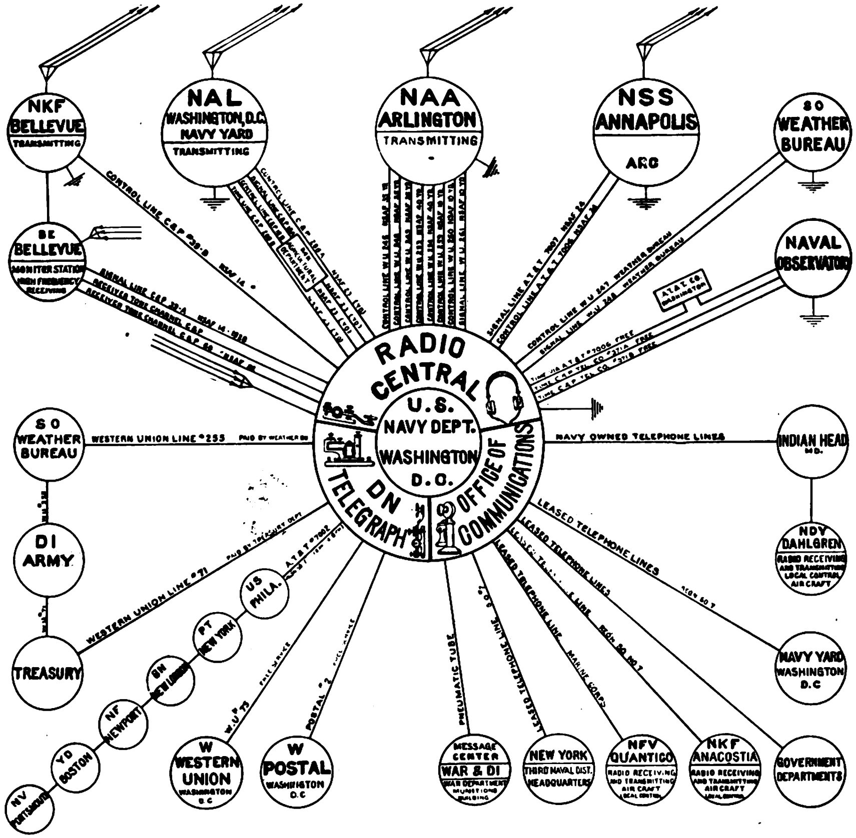

Fig. 1—Naval communication system. Washington, D. C. Chart Note: Bellevue (NKF) transmitters use call NAA when controlled from Navy Dept. Navy Yard broadcast transmitter uses call NAA. All *R/T* weather broadcasts are keyed from the Weather Bureau, and time signals from the Naval Observatory.

his position. Such an arrangement further enables the supervisor to keep himself informed of the progress of work at all times without disturbing the operators to make inquiries.

The control board, which is 75 in. high and 40 in. wide is completely shielded throughout. Mounted on its front are two meters for measuring the control and signal line current and voltage. About four hundred standard telephone switchboard jacks are installed to permit the use

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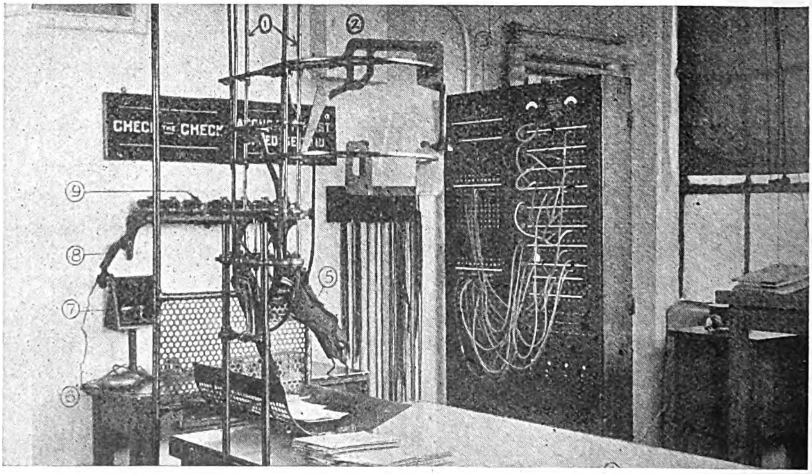
of patch cords for maximum flexibility. The total length of lead cable within the board exceeds 1500 ft., and there are about 4,000 soldered connections on the rear of the panel.

An open, shorted, or grounded circuit on any control or signal line between Radio Central and the various transmitters will be immediately evidenced to the supervisor by the ringing of a buzzer alarm which is common to all lines, and a signal lamp which shows red over the terminal jack of the line. The board is equipped to permit paralleling or grouping of the several transmitters for simultaneous transmissions on any one circuit. Added features will permit the super-



Radio Central, Navy Department, Washington, D. C. View of supervisor's desk, message carrier, sounder shelf, and control board. (1) Vertical carrier drop. (2) Clock circuit switch and relay box. (3) Control board. (4) Supervisors' desks. (5) Message holder. (6) Carrier guard. (7) Signal line sounder. (8) Inter-phone hand set. (9) Relays used as sounders.

visor to connect any one or more operating positions to any control or signal line, and also to any listening or operating receiver. Non-inductive resistors and condensers connected in series are shunted across the various control and signal lines to eliminate key click interference to receivers.

Because of the high noise level in summer which obtains at the Navy Department on high frequencies during office hours, due to stray currents from fans, automobiles, x-ray machines, etc., it was necessary to establish a receiving station at Bellevue so that uninterrupted service could be maintained. High-frequency signals, between 8:00 A.M., and 12:00 P.M., are thus "tuned in" at Bellevue and

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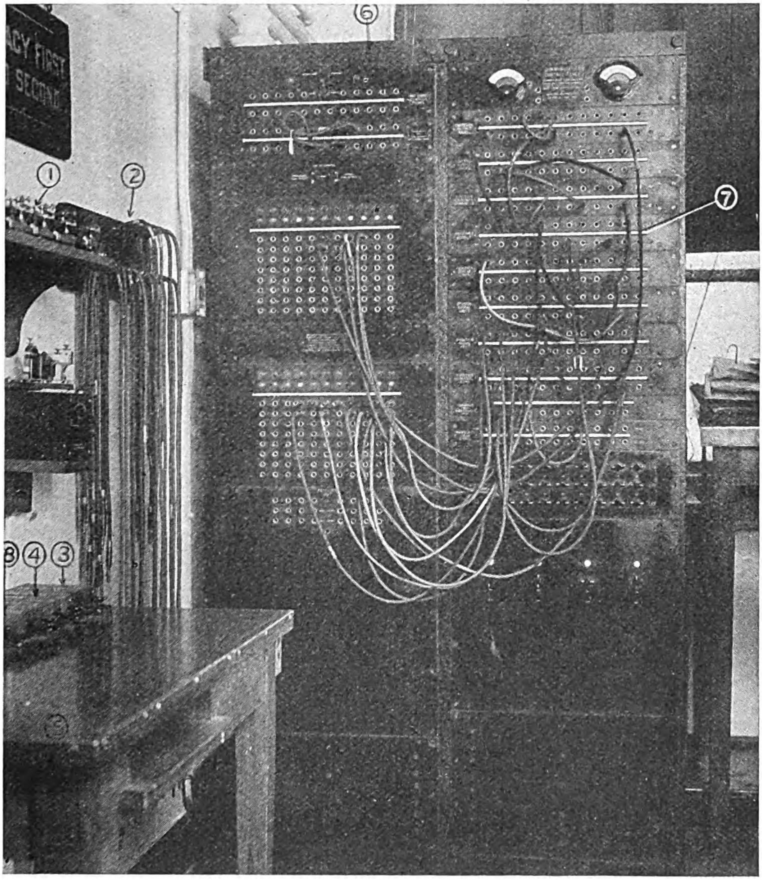
there amplified and monitored over a leased telephone line to the operator's ear phones at Radio Central.

The receivers in use at Radio Central are of a standard type used throughout the Naval Service.



Radio Central, Navy Department, Washington, D. C. Front view of control board. (1) Bunnell relays used for sounders. (2) Patch-cord rack. (3) Test control key. (4) Signal line key. (5) Supervisors' telegraph table. (6) Control board. (7) Patching cord. (8) Building intercommunication key.

The frequency band 10 to 1,000 kc is covered by the two types of receivers of the same mechanical design,—the intermediate-frequency type of receiver having a tuning range of 75 to 1000 kc, and the low-frequency type a range of 10 to 100 kc.

Intermediate- and low-frequency receivers consist of four major

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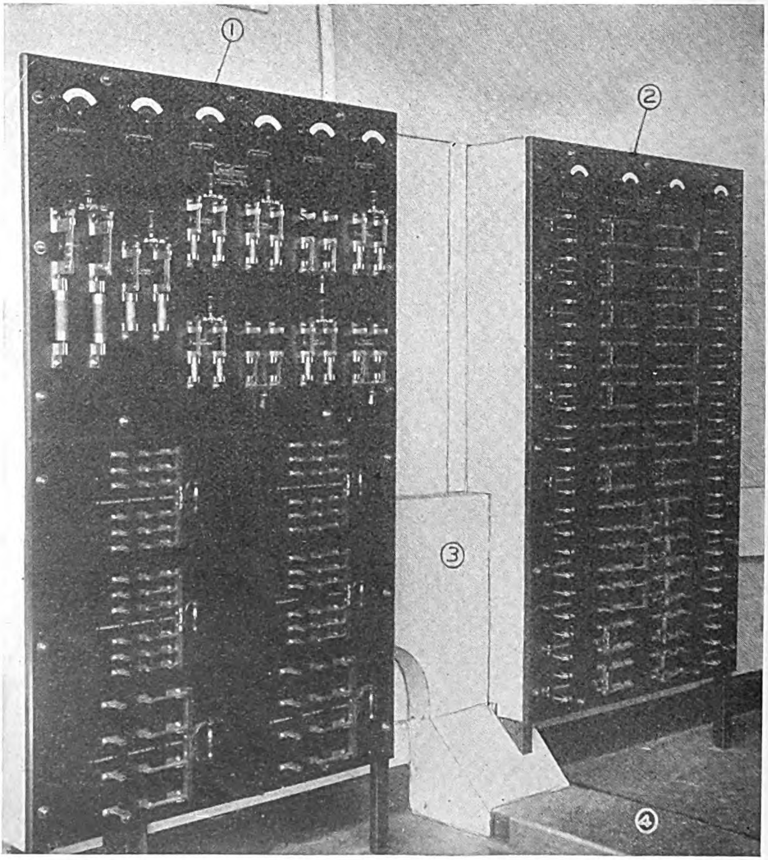
units completely shielded; namely,—antenna coupling unit, four-stage untuned radio-frequency amplifier, regenerative receiver, and two-stage audio-frequency amplifier,—set up from left to right in the order named. Seven Western Electric tubes are used in each complete receiving equipment. The high-frequency type of receiver which is



Radio Central, Navy Department, Washington, D. C. Front view of battery charging panel and battery distribution panel. (1) Charging panel. (2) Distribution panel. (3) Steel cable trench. (4) Steel cable trench.

completely shielded and similar in mechanical design to the low— and intermediate-frequency receiver, consists essentially of a single neutralized stage of tuned radio-frequency amplification capacitively coupled to a tuned autodyne detector circuit, and two stages of audio-

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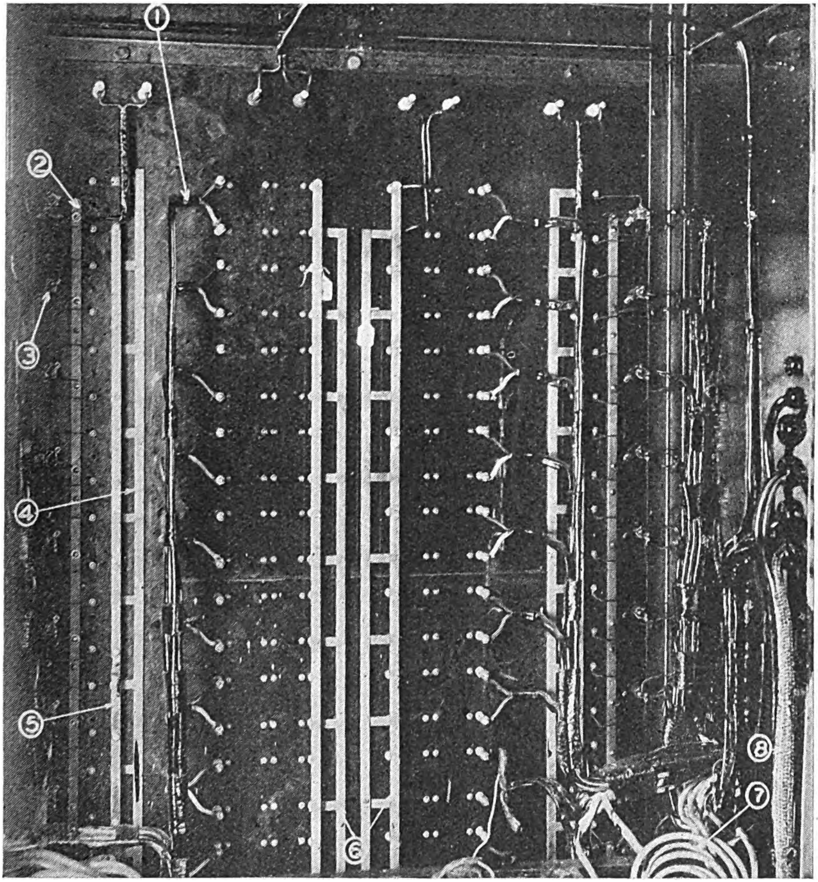
frequency amplification. Five sets of plug-in coils covering the range 1,000 to 20,000 kc are supplied with each receiver.

Both the Creed and Kleinschmidt type of perforators and trans-



Radio Central, Navy Department, Washington, D. C. Rear view of battery distribution panel with door open. (1) Filament supply cables to positions. (2) Minus plate battery and ground bus. (3) Plate battery switch. (4) 90-v bus. (5) 45-v bus. (6) 2-v busses. (7) Spare cables. (8) Belden braid shielding over rubber-covered wire.

mitters are used. Automatic tape reception is accomplished by means of the RCA power amplifier and ink recorder equipment.

Photoradio equipment for transmitting and receiving photographs 5 in. by 7 in. has recently been installed and is being used for experimental work.

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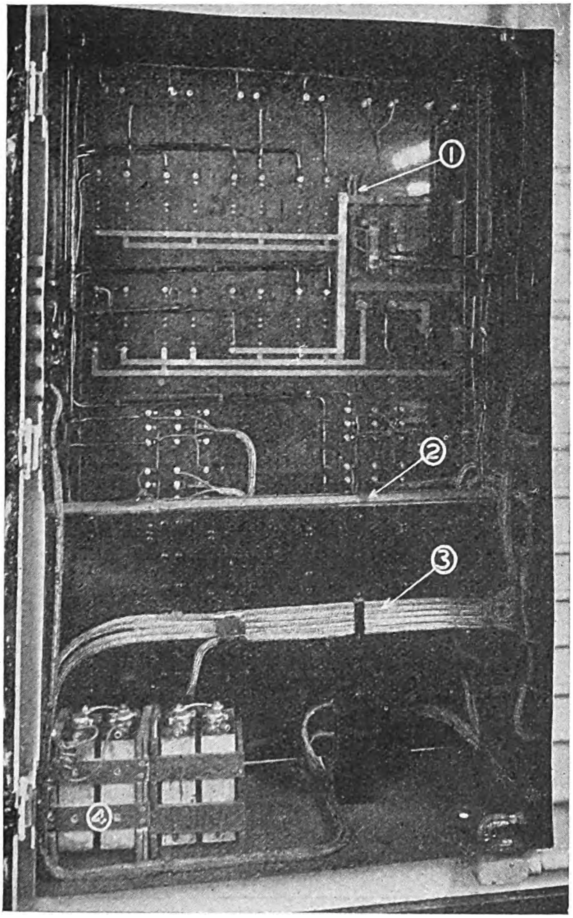
keeping the desired signals tuned in and connected to the leased telephone wires which lead to Radio Central where operators copy the message direct on the typewriter.

A signal line employing a Morse sounder is used for signaling purposes between the stations.



Radio Central, Navy Department, Washington, D. C. Rear view of battery charging panel, door open. (1) Ammeter shunt resistor. (2) Steel cable trench. (3) Belden-braid shielding on rubber-covered wire. (4) Batteries for clock.

The leased telephone lines, or tone channels, are run underground in a lead cable from the Telephone Company's pole outside the Bellevue reservation for a distance of approximately 500 ft. to the monitor station.

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Two transmitters of crystal control design are installed in the machine shop of the Research Laboratory. These transmitters are used primarily for experimental work, except at night when traffic conditions demand they are controlled from the Navy Department Radio Central.

The control line leading to the Bellevue Laboratory is also used to give new transmitters a service test in handling traffic from Radio Central, prior to releasing the transmitters to the ships or stations for which they were developed.

Annapolis

Across the Severn River from the U. S. Naval Academy, there is situated the U. S. Naval High Power Radio Station, Annapolis, Md., which was first commissioned on August 6, 1919. The station is located about three miles by paved highway from the city of Annapolis on a tract of land comprising thirty-eight acres. This location was chosen because of its close proximity to the Navy Department for economical remote control, and yet distant enough not to interfere with reception at Radio Central in the Department.

Towers

The six Annapolis steel towers are triangular in plan, 600 ft. high, and rest on concrete foundations. They are designed to withstand a maximum safe horizontal pull (at top) of 20,000 lbs. Four of the towers are spaced on a rectangle, 860 ft. square, the remaining two being spaced laterally 975 ft. and 1,250 ft. measured on the longitudinal center line. The six towers thus appear to the casual observer as being arranged in two rows of three each.

Antenna System

The antenna is supported by 5/8-in. plough steel triatic cables suspended between the towers. Each of the three triatics is insulated from the towers by double porcelain strain insulators. The antenna connections are such that the triatic cable is normally at antenna potential. Antenna wires are secured to the outer end (south) triatic and are run through special antenna wire sheaves on the middle and north triatics from which they lead to an anchorage tower and to the entering arrangement on the roof of the helix room. The sixteen antenna wires, where secured to and crossing the triatics, are insulated therefrom with 10-in. disk suspension insulators, except antenna wires number three, five, and eleven which are bonded to triatics number one, two, and three, respectively, to maintain the triatics at antenna potential.

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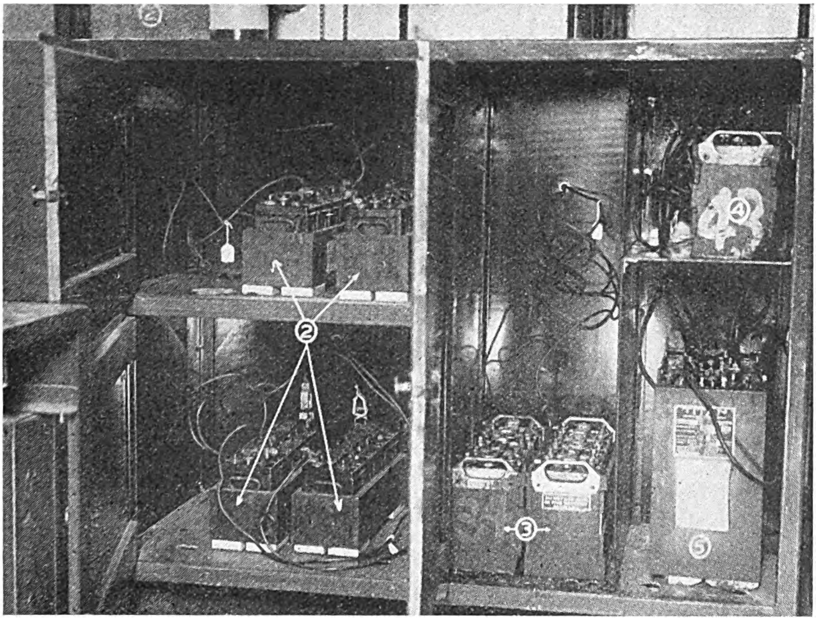
The antenna is insulated for a maximum of 50,000 volts and has a fundamental frequency of 191.6 kc.

Because of the extremely high mechanical loads which the triatics are required to carry, together with the high voltage current applied to the antenna, it was necessary to develop a special porcelain tubular insulator ten ft. in length. These insulators are designed to withstand an ultimate strain of over ten tons, and an electrical flash-over voltage, when dry, of about 190,000 volts at a frequency of 50,000 cycles.



Radio Central, Navy Department, Washington, D. C. View showing right half of battery locker with doors open. (1) Steel cabin. (2) 45-v plate batteries. (3) Signal batteries. (4) Battery for Marshall receiver 6-v filament. (5) 2-v filament batteries.

These insulators act as safety links to prevent overstressing the towers should excessive weight be added to the antenna by the formation of ice on the wires and supporting triatics, or by excessive strain from high winds. The insulators will fail before the tower breaking point is reached, thus causing the antenna to fall to the ground and thereby prevent overloading and possible collapse of the towers.

The maximum sag of the antenna wires with their supporting triatics is 115 ft. while the electrical effective antenna height as measured was found to be 360 ft.

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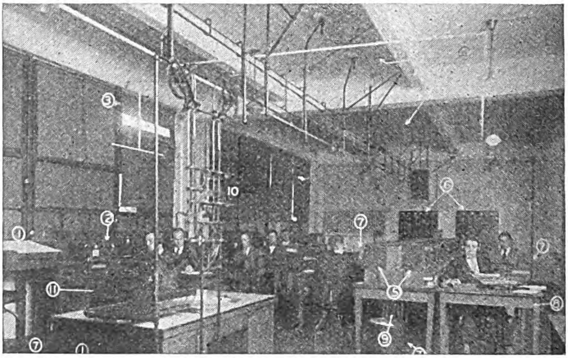
The 20-kw tube antenna system consists of two fans of four wires each, stretched at an angle of 45 deg., and supported by a silicon bronze 3/8-in. cable running between the two north towers. At a distance of 75 ft. from each tower the cable is broken by porcelain strain insulators. The lower ends of each fan converge at insulators about 150 ft. above the tube transmitter house from which point a single 3/8-in. cable is led to two steel anchor posts north of the transmitter house where the lead-in wires are taken off at right angles and connected to the transmitter.



Sectional view showing operating positions. Radio Central, Navy Department, Washington, D. C. (1) Supervisors' desks. (2) RG receivers. (3) Lead-in insulators and lightning arrestor. (4) Antenna lead-in wires. (5) RE and RF receivers. (6) Battery panels. (7) Steel cable trench. (8) Operator's typewriter and key table. (9) Cable conduit. (10) Vertical drop of message carrier. (11) Message carrier guard.

The Ground System

Two ground systems totalling 36 miles of wires are installed, one system being for the 500-kw arc transmitting equipment, and the other for the 20-kw tube transmitter.

The main ground system for the arc transmitter consists of 240 No. 12 copper wires radiating in all directions from the power house. The wires are buried approximately six in. in the ground and are led from the power house to their outer ends where they are soldered to one seven-strand copper wire which encircles the area encompassed by the two center and two north towers. This encircling wire is about 700 ft. from the power house.

The 20-kw tube ground system consists of 8 No. 12 copper wires, buried approximately 3 in. underground, in a fan shaped formation, the apex being at the tube house and the wires running under the tube antenna. Under the concrete foundations of the tube house,

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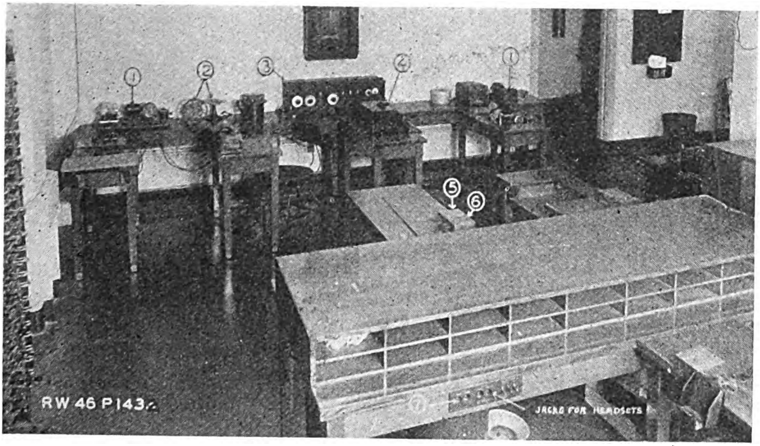
5 strands of No. 0 copper wire are connected to the apex of the fan shaped ground system. The far ends of the fan system are interconnected by a single strand of No. 0 copper wire. Running in a straight line from the apex of the fan ground system at the tube house to the northwest tower are 3 No. 0 wires buried in a trench 2 ft. deep; three similar wires running to the transformer house in a trench 1 ft. deep, and two wires buried in a trench running in the direction of the northwest tower.



Radio Central, Navy Department, Washington, D. C. View of operating room, showing high speed transmitters, recorders, tone amplifier, Klienschmidt perforator and tape puller. (1) High speed transmitter. (2) Tape rolls. (3) Tone amplifier. (4) Tape perforator. (5) Position 20-signal key. (6) Position 20-control key. (7) Jacks for keys.

The arc and tube ground systems are connected at all intersections.

Ice Melting System

A special ice melting system is installed to prevent accumulation of ice on the antenna.

Close observation of weather conditions, temperature, and occurring changes in frequency are required to determine when ice is forming on the antenna. Even an experienced observer has difficulty at times in forecasting probable ice accumulation. The only certain method of guarding against serious casualties to the antenna as a result of ice is to apply the ice melting current during sleet or rain every hour for twenty consecutive minutes whenever the temperature is between 27 deg. and 32 deg.

Melting ice on the main antenna is accomplished by switching

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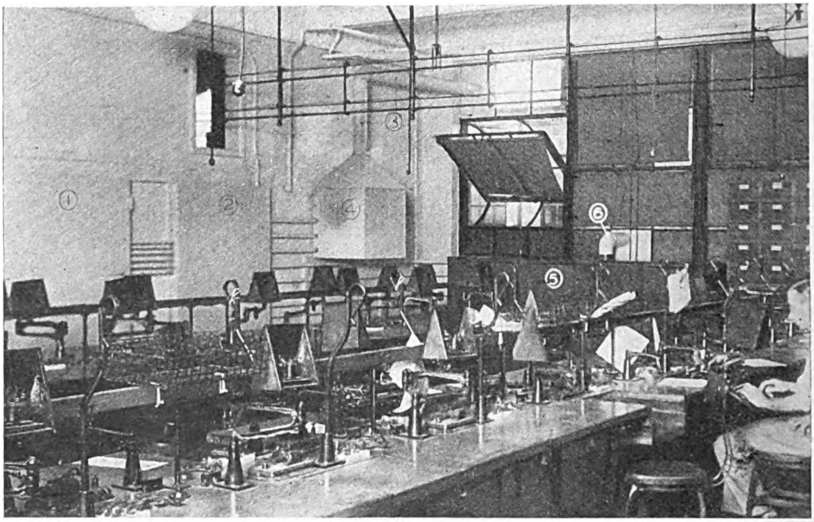
the antenna into two series sections, paralleling these two sections and applying 325 amperes direct current at 1,000 volts to the series parallel circuit, the power being obtained from any one of the three arc motor generator sets.

To provide ice melting for the 20-kw tube antenna, a 400-kw arc motor generator supplies 250 amperes direct current at 125 volts through a special switching arrangement to the antenna.



Radio Central, Navy Department, Washington, D. C. View taken in wire room showing the rear view of battery distribution and charging panels closed, charging resistor unit and battery locker. (1) Battery distribution panel. (2) Battery charging panel. (3) Hot-air vent pipe. (4) Battery charging resistance box. (5) Battery cabinet. (6) Battery vapor exhaust pipe.

Electric Power Supply

The electric power supply is obtained from the Annapolis and Chesapeake Bay Power Company's substation in Annapolis, at 33,000 volts, 3 phase, 25 cycles. The power is actually generated, however, at the Bennings, Washington, D. C., power house. Three 333-kva 20-cycle transformers owned by the Navy are installed in the Annapolis substation.

Transmitters

The transmitting equipment installed in the Annapolis station consists of one 20-kw tube transmitter, and two 500-kw arc radio transmitters complete in duplicate throughout to guard against possible interruption to service due to possible failure of one.

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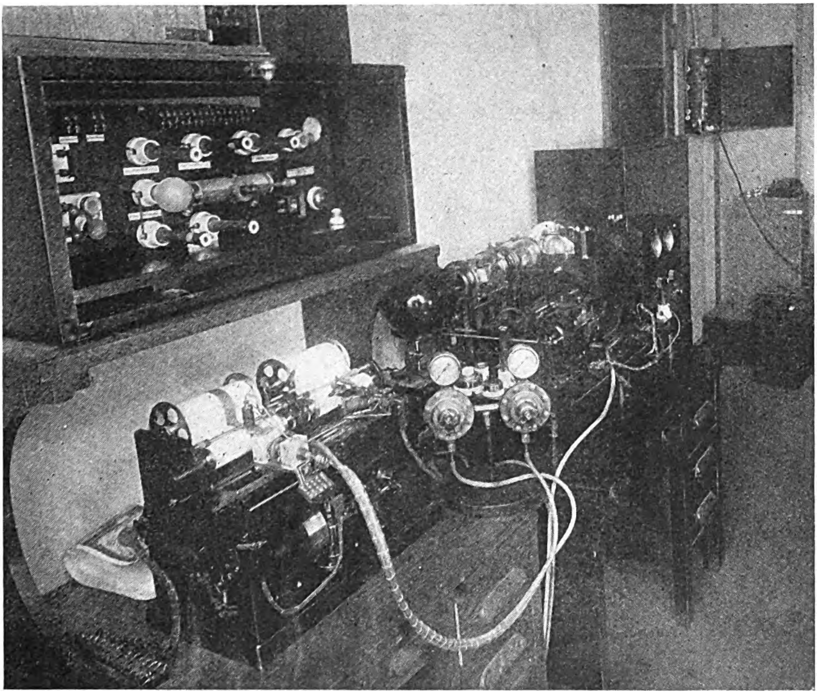
The arc radio transmitters are of the Federal-Poulsen design of arc converter, originally produced in Denmark, but later developed and perfected in the U. S., and are based on a method of obtaining radio-frequency current oscillations by means of an electric arc burning in an airtight chamber containing hydrogen.

The essential items of the Federal-Poulsen arc converter comprise an airtight chamber of bronze, a "positive" electrode of copper, a "negative" electrode of carbon, two electromagnetic iron pole tips,



Radio Central. Photoradio.

and a hydro-carbon feed supply. The electric current supply of 1,450 volts direct current is converted from 2,200 volts 25 cycles alternating current from either the 750-kw motor generator, or from the two 400-kw motor generators operated in parallel.

The main loading inductance used in the arc transmitter consists of two coils of thirty-two turns each mounted on one helix supported by thirteen insulator columns. The average space between turns is $3\frac{1}{4}$ in., and the diameter of the outside coil of the helix is 13 ft. 9 in.

The conductor used in constructing the loading coil is a special

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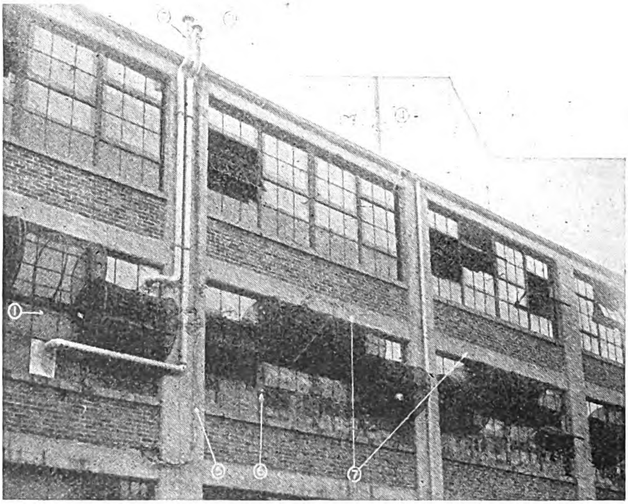
radio-frequency cable consisting of 10,656 strands of No. 36 enameled wire. This wire is stranded 18 by 16 by 37.

A special high tension condenser of 78 plates (40 high tension, 38 low tension) is used in the arc current transformer circuit. The size of each plate is 18 ft. by 11 ft. 9 in., and is constructed of brass pipe frames covered on one side with inch mesh wire netting and soldered and seized at all intersections.



Radio Central, Navy Department, Washington, D. C. Outside view showing entering insulators, battery vent, and charging resistor heat exhaust. (1) Wire room. (2) Hot air pipe from resistor box (3) Battery vapor vent. (4) Antenna: lead-in wire. (5) Cables from roof. (6) Lead-in insulator. (7) Radio central.

Tube Transmitter

The 20-kw transmitter is distantly controlled by the Army from the War Department, Munitions Building, Washington, D.C.

Power supply for this transmitter is taken from 6,600 volts three-phase 25-cycle line and stepped down to 220 volts. The 220 volts alternating current is rectified into direct current by means of twelve Kenetron rectifier tubes, which supply the d-c plate current for the oscillator tube.

The rectifier output voltage is variable from 7,000 to 15,000 volts direct current and is regulated by a switching device which changes the number of primary turns of the rectifier transformer.

One 20-kw tube is used as an oscillator, and is keyed in the grid circuit. Through the keying system a negative bias is applied to the

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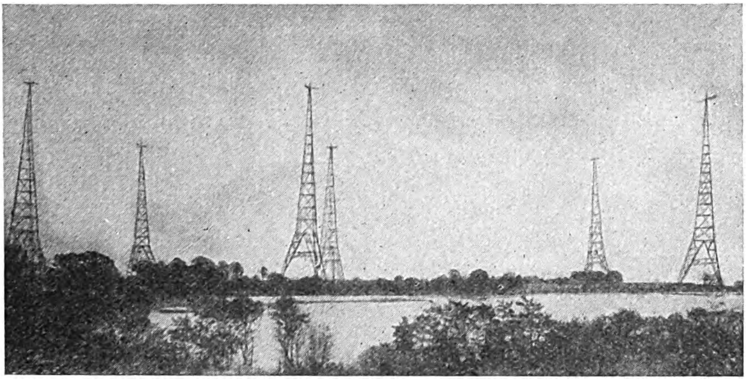
grid of the 250-watt tube, which in turn, according to key position, governs the oscillation of the tube.

The oscillator is connected to a modified Hartley circuit, the primary of which is coupled to the antenna by means of condensers.

Filament current for the rectifier and oscillator is obtained from an a-c supply through step-down transformers. The grid d-c supply is obtained from the 220-volt transformers and two 50-watt rectifier tubes.



Annapolis, showing 600-ft. towers viewed from west.

Signaling System

The Annapolis station NSS main arc signaling system is operated by means of a leased control line from Radio Central of the Navy Department. An additional leased wire known as the signal line is used for communicating between Radio Central and the Annapolis station, and as an emergency control line if desired.

The control line is looped through the station from the Annapolis telephone office and is connected at the radio station with two standard telegraph relays and a local hand key. One of these relays is connected with the key on the operator's desk in the arc room for local control, and the other forms part of the high speed key system panel, its secondary being connected to the coils of a polarized master relay. The secondary of the master relay controls ten polarized relays of a similar type. Three of these control three groups of six main keys, each located in the circuit across the nodal point resistance in the radio-frequency circuit; five polarized relays control five groups of four keys each, which are connected in series with the power balance loop and resistance of the radio-frequency circuit. The action of these

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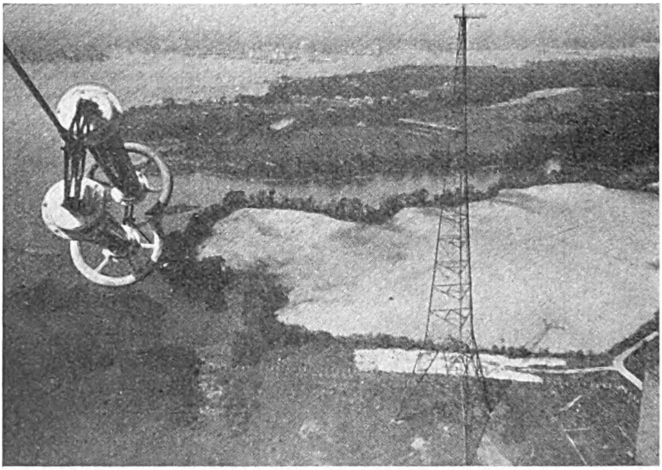
eight groups of main relay keys produces a uniwave system without sparking. The two additional main relay circuits are used as spares, and for key testing from the electric shop.

Power Outfits

Twenty-nine miscellaneous power outfits are installed at the station for auxiliary purposes. There is also installed an auxiliary power



Annapolis, showing triatic insulator in position and suspension insulators on triatic number one viewed from top of tower.

plant consisting of steam boiler, reciprocating engine, generators, etc., to supply emergency power for lighting and ice melting, and for supplying heat and hot water to the station.

Arlington

The U. S. Naval Radio Station, Radio Virginia, generally referred to as "Arlington" or "NAA" was first placed in active commission on 13 February, 1913 and was the first high power radio station owned by the Navy Department.

The original installation at Arlington consisted of a 100-kw Fessenden spark transmitter using a synchronous rotary spark gap.

The original receiving equipment of the station was of the crystal and electrolytic type, and all receiving took place at the station rather than from a distantly controlled Radio Central as is now being done.

Arlington ceased to be a receiving station on November 5, 1915 when the Navy's first remote control Radio Central was established

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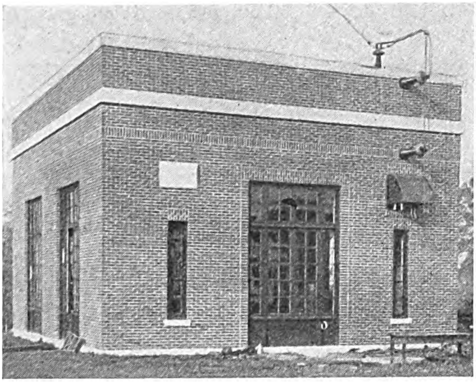
in the Navy Department at the State, War and Navy Building in Washington, and since that date Arlington has been used only as a distantly controlled transmitting station.

The Arlington Station is located about four and one half miles from the Capitol in Washington. The ground, 13.4 acres, was transferred from the War Department to the Navy Department by act of Congress. Three additional acres of ground adjoining the station were purchased in 1917 making a total of 16.4 acres. The average elevation in the vicinity of the towers is 190 feet above sea level.



Tube transmitter house. NSS. Showing lead-in for transmitting and ice melting.

TOWERS

The three main towers, one 600 ft. high from the ground, and two 450 ft. high, are of ornamental steel construction. The centers of the towers form an isosceles triangle, the base of the triangle being 350 ft. long and the altitude 350 ft.

Each tower is constructed on four legs, the base of which is mounted on a concrete foundation about six ft. square at the top, gradually increasing in size until at the bottom, 14 ft. from the top, it is 12 ft. square.

Each tower leg is insulated from the ground by means of a large marble slab and marble washers. These slabs have been tested up to 150,000 volts. The legs are securely grounded, however, by means of a copper cable which may be disconnected at will.

The 600-ft. tower is estimated to weigh 444.5 tons and the 450 ft. towers 275 tons each. The towers are designed to withstand a maximum safe horizontal pull (at top) of 10 tons.

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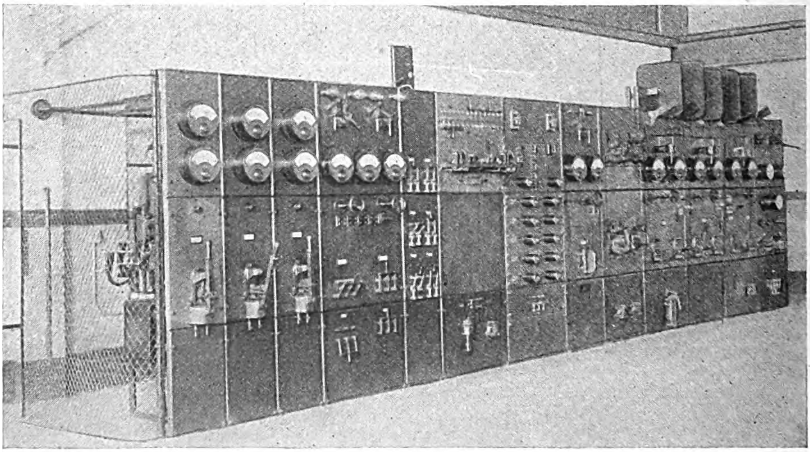
In September, 1922, two new towers were erected, one about 200 ft. east of the south tower, and the other about 800 ft. east of the north tower. They are of steel construction, 190 and 200 ft. high, respectively.

The Antenna System

There are eight entennas in use at the Arlington Station, four of which are used for high-frequency transmitters and four for the intermediate- and low-frequency transmitters.

The largest or main antenna is supported by the three main towers and is used with the 20-kw tube transmitter.



The converter room, Annapolis, Md., showing main switchboards.

The 10-kw tube transmitter antenna is supported by the north 450-ft. and the northeast 200-ft. towers. The antenna for the 1.5-kw tube transmitter is supported by the south 450-ft. and southeast 190-ft. tower, and the antenna for the 1-kw tube from the north 450-ft. and the southeast 190-ft. tower.

High-frequency antennas are supported from the north 450-ft. tower and 2-in. galvanized iron pipe masts on the roof of the transmitter building.

The main antenna, constructed in December, 1926, by station personnel, consists of 15,000 ft. of No. 12 silicon bronze and antenna wire, supported from the 600-ft. tower by two spreaders and two double porcelain strain insulators. A wire cable, three quarters of an inch in diameter, is stretched between the two 450-ft. towers to support

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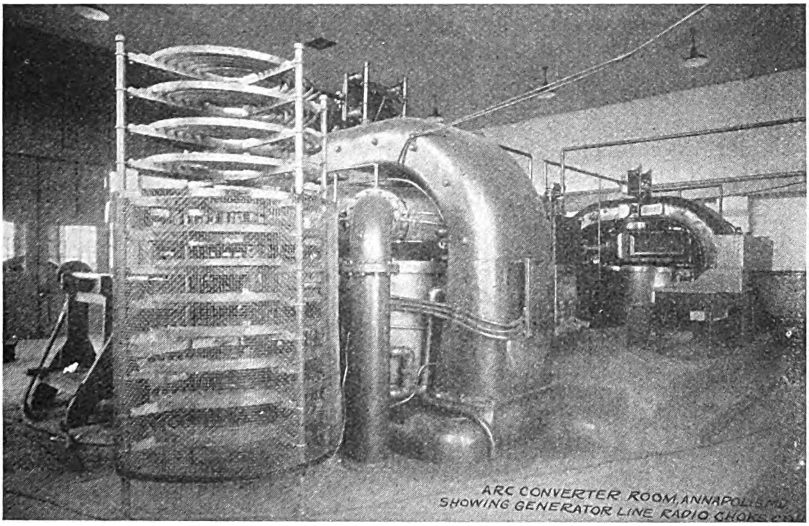
the lower part of the fan-shaped antenna. This cable is insulated from each tower by one double porcelain strain insulator.

The flat top consists of sixteen wires which are secured to the two spreaders at the top of the 600-ft. tower and then rove over a brass block attached to the triatic cable where they are divided into two sections of eight wires each, and lead down in four fans to the lead-in arrangement.



Arc converter room, Annapolis, Md. Showing generator line radio choke coils.

The Ground System

The Arlington ground system consists of several miles of No. 12 copper wire buried at various depths in the ground under the main antenna. These wires form a checkerboard pattern and are soldered at each intersection. Strips of copper, 6 in. wide and $\frac{1}{4}$ in. thick, were laid under the foundation of the building when they were first erected. These strips are connected to the network ground system which extends in all directions from the transmitter building.

Electric Power Supply

The Virginia Public Service Company of Alexandria, Va., supplies the Arlington station with 3-phase, 13,200 volts, 60 cycles power which is stepped down to 220–440 volts through three 333-kva transformers.

Additional power at 25 cycles, single phase, 6,600 volts is supplied

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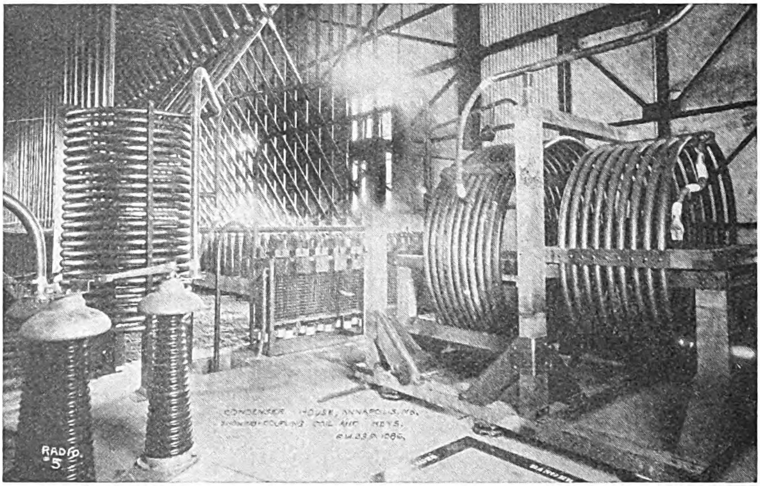
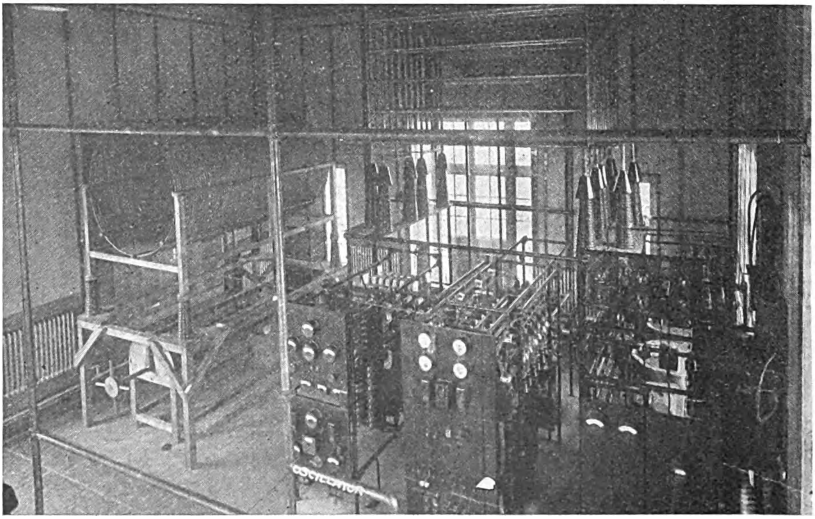
by the Potomac Electric Power Company of Washington, D.C., and is stepped down to 250–440 volts through three 50-kva transformers.

TRANSMITTERS

The 20-kw tube transmitter, which was first placed in active commission on July 1, 1925, consists essentially of a single-phase 60-kw



Condenser house, Annapolis, Md. Showing coupling coil and keys.



20-kw tube transmitter NSS. Closed circuit assembly.

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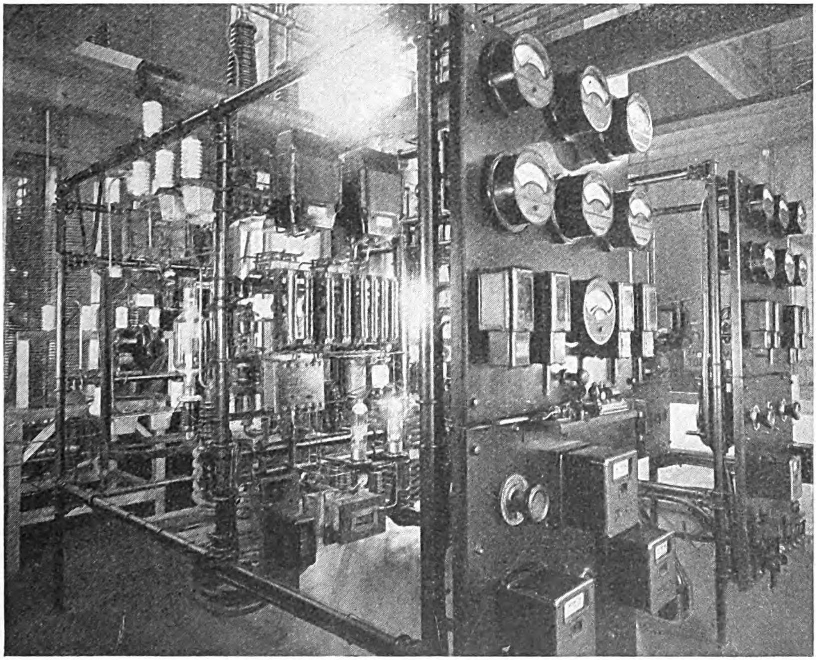
rectifier, supplied by either the 100 or 60-kw 500-cycle alternators formerly used on the NAA spark transmitters. The 500-cycle supply is stepped up from 220 to 36,000 volts rectified by two water-cooled tubes, type UV214, and delivered at 15,000 volts direct current to a master oscillator power amplifier circuit consisting of one 5-kw tube as a master oscillator, and two 20-kw water-cooled tubes as power amplifiers. These tubes supply a tank or closed circuit, which feeds the antenna system by capacity coupling.

This transmitter is used almost exclusively at the present time for communication with San Juan, Porto Rico.



NAA 20-kw tube transmitter. December, 1925.

The 10-kw tubé transmitter is not of the master oscillator type. The 500-cycle supply for this transmitter is rectified by two type UV219 tubes and is then supplied to the plate of a 20-kw oscillator tube. An inverse time limit relay system breaks the d-c source for the radio telegraph relay. Inasmuch as this relay makes and breaks the primary of the 500-cycle transformer, no 500-cycle supply can be applied to the transmitter until the radio telegraph relay is energized.

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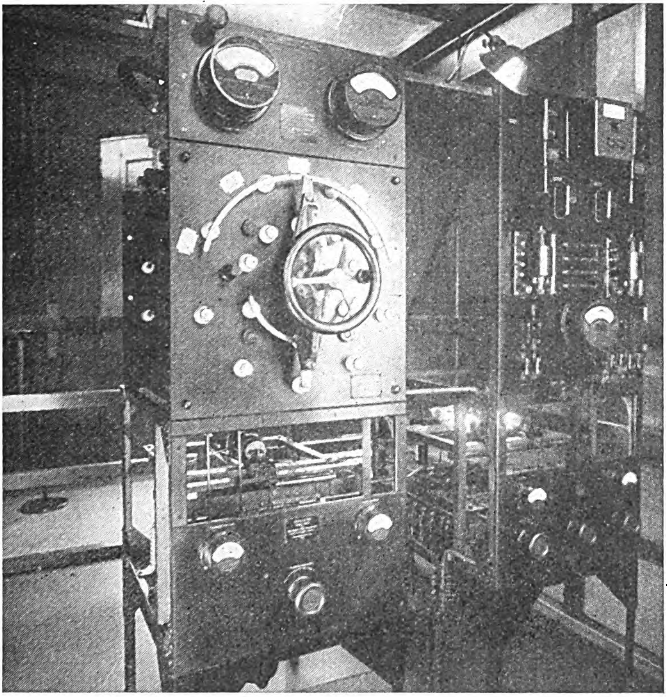
The 10-kw tube transmitter is calibrated to operate on three frequencies. The first two of these frequencies are used on the New York, Philadelphia, Norfolk, Charleston, Washington circuit, and the latter frequency for daily broadcasts of weather, press, etc.

The 1.5-kw tube transmitter is operated by remote control from Bolling Field and is used exclusively by the Army.



NAA 1-kw tube transmitter. December, 1925.

This transmitter rectifies the 500-cycle supply by means of two UV218 rectifying tubes which supply is applied to the plate of one 5-kw UV208 oscillator tube. The transformer has a five-point frequency change switch for rapid change of frequency.

The 1-kw tube transmitter rectifies the 500-cycle supply by means of two UV218 rectifying tubes and applies it to the plate of one 1-kw UV851 oscillator tube.

Keying of the 1.5-kw, and 1-kw transmitters is identical to that of the 10-kw transmitter. Inverse time limit relay system is also similar.

The 1-kw tube transmitter is operated by the Department of

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Commerce, Airways Division, by remote control from Washington.

The NAA Broadcast Transmitter operated on 690 kc and is located at the Washington Navy Yard.

This set is rated at 1 kw, using a 50-watt tube for the master oscillator, and one 1-kw tube as a power amplifier. Modulation is obtained by modulating the output of the 1-kw power amplifier by means of a second tube of similar stype.

Four high-frequency transmitters were installed in 1927 and these were developed by the U. S. Naval Research Laboratory, Bellevue, D.C.

The transmitters now installed are of crystal control and each transmitter has its individual 10-kw motor generator set to supply 10,000 volts direct current to the plate.

ACKNOWLEDGMENT

E. K. Jett, lieutenant in the U. S. Navy, aided in the preparation of this paper.

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MICROPHONIC IMPROVEMENT IN VACUUM TUBES*

By
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Summary—*The paper contains a discussion of the causes and effects of microphonic disturbances in small receiving tubes and the nature of these disturbances, and gives methods of testing for microphonic disturbance whereby the sources of the disturbance may be located and corrected, as well as methods of testing tubes as a means of comparison of individual tubes of different types. A new type of tube with low microphonic output but with low filament power for uses where microphonic troubles may be serious is also described and its characteristics are given.*

MICROPHONIC effects are usually considered to include all of that class of noises in a vacuum-tube output circuit which are due to external disturbances acting upon the tube in some fashion other than through the electrical circuits. Microphonic output is caused by relative motion between the various elements of the tube with resultant variations in plate current due principally to change of plate resistance of the tube.

In the past the only important occurrence of microphonic difficulties has been in radio receivers where acoustic feedback has occurred between the loud speaker and the small receiving vacuum tubes. The more recent application of vacuum-tube equipment in positions where the tubes are subjected to considerable vibration has resulted in the appearance of new and more serious problems of microphonic response that require investigation.

Vibration of vacuum tubes in receiving sets may be excited by sound waves in the air reaching the bulb or by waves transmitted from speaker to tube through the cabinet, socket, and tube base. The variation in microphonic response between different receiver arrangements has resulted in considerable attention being paid to mounting and shielding to prevent microphonic difficulties. Spring suspension of the socket and covering of the bulbs with caps lined with sound absorbing material have been among the most useful examples of such work. However, such shielding is of limited possibility in sets subjected to severe vibration, as for example, aircraft receivers. In such receivers flexibility of tube mounting is limited by the effect of displacement of the tube itself on radio-frequency circuits before acoustic isolation is attained. Packing with sound absorbing material is likewise limited because of space restrictions. For satisfactory operation under such

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severe service lower microphonic response of the tube itself is required. The possibilities of such improvement are considered in this paper.

Methods of Microphonic Testing

The simplest test for microphonics consists of an audio-frequency amplifier of fairly high gain, the tube under test being used in the first stage. If the tube is struck with the finger the output from the amplifier may be heard in a loud speaker. The relative loudness and the time of damping of the sound wave serve as a means of comparison of the tubes. This test depends upon the judgment of the operator and the severity of the blow. Such a test may be used in comparing different lots of vacuum tubes of the same general type, although obviously, different operators will not agree exactly upon the merits of tubes and the test is therefore of no quantitative value.

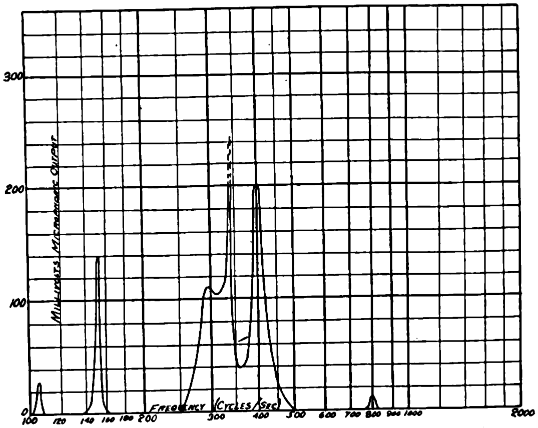

Fig. 1

The above test may be modified by directing the loud speaker towards the tube. A howl from acoustic feedback may be built up if the tube is close enough to the loud speaker or the socket is sufficiently rigid to transmit vibrations from the speaker. If the initial sound dies out in two or three seconds under this test the feedback will not generally be serious. Although this test may be used in checking uniformity of a vacuum-tube production it still does not give a quantitative measure of microphonic response. The absence of a howl in one circuit is not necessarily an indication that one will not be built up in another circuit. For test purposes the tube mounting and speaker distance must be adjusted to give the best possible percentage cor-

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relation with actual receiver performance. This discrepancy between a test circuit and receiver performance is even more pronounced in modern broadcast receivers with built-in speakers. In such combinations the acoustic characteristics of the cabinet and location of the

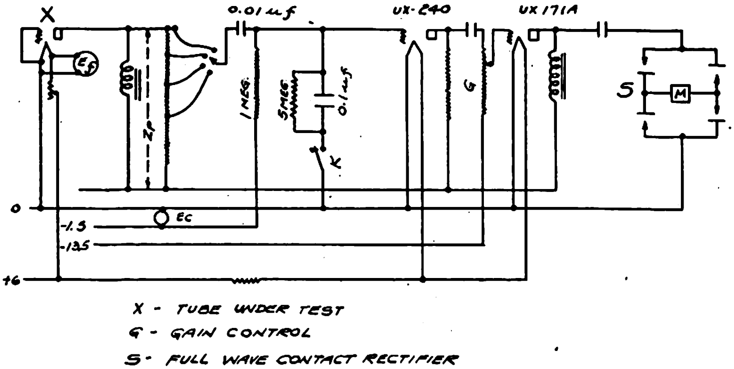

Fig. 2

components will determine the possibilities of tube response in the particular equipment. Individual receivers of the same type may vary so considerably that the tubes quiet in one receiver may build up sus-

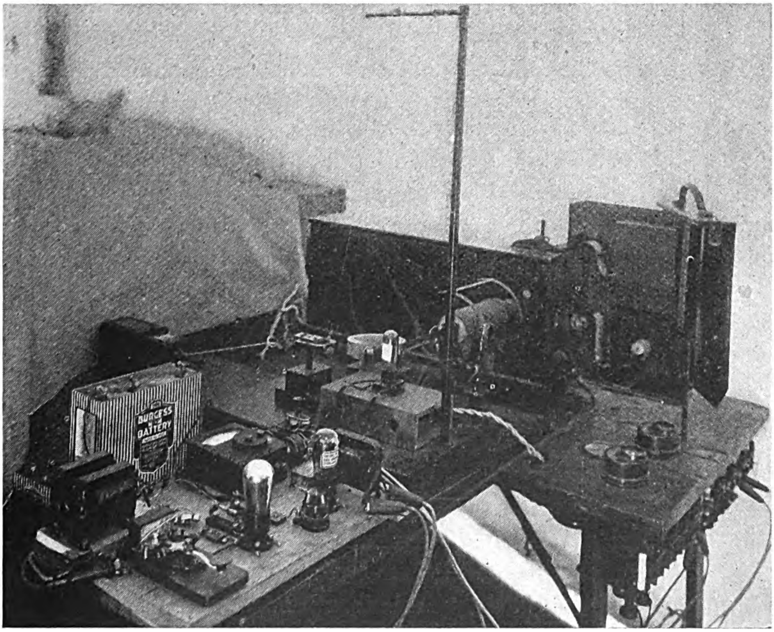

Fig. 3

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tained howls in the other. As a consequence, tests of tubes in such a receiver do not show whether the tubes or the receiver itself are abnormal.

For the determination of the effect of forced vibrations a test has been devised in which the tube is strapped to the moving element of a moving coil loud speaker which is excited from a variable frequency

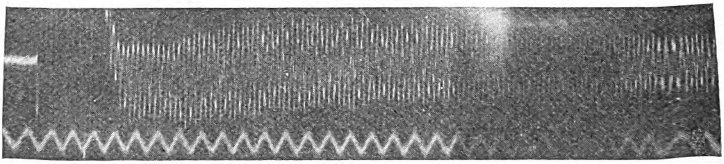

Fig. 4

oscillator. Microphonic output voltage across the plate circuit load is measured by a tube voltmeter and plotted against frequency. The resultant graph forms a vibration spectrum consisting of peaks at the resonant frequency of the various parts of the tube. Although a few peaks are quite broad the greater number are very sharply defined

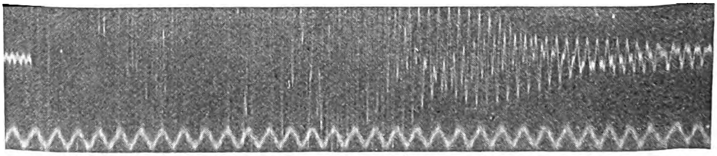

Fig. 5

and easily missed in measurement unless the operator detects them by the sound in head-phones in the voltmeter circuit. Other tests have shown that a number of large peaks indicate a tube which will be poor under operating conditions. This method enables the location

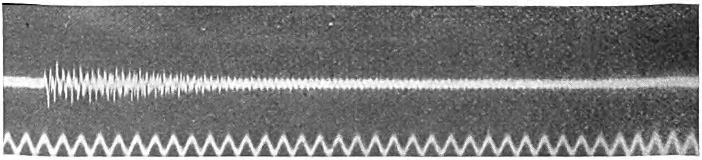

Fig. 6

of the principal source of disturbance since whenever a large peak occurs one or more of the elements of the tube can be seen to be vibrating quite strongly. A typical vibration frequency record is shown in Fig. 1.

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This vibration test is useful but does not give an adequate criterion of the disturbances in the output circuit when the tube is subjected to shock excitation. The number and magnitude of resonance points may be used as a rough measure of possible microphonics, but the difficulty in determining the peaks of the resonance points prevents the use of the readings for quantitative comparisons. For this reason a ballistic impact test has been developed as the best means of obtaining a definite reading to indicate the merit of the tube. The impact is

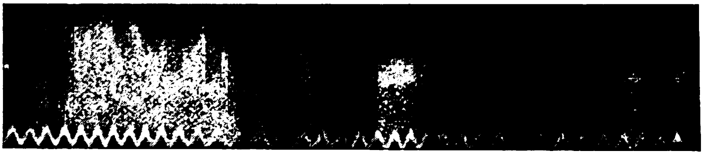

Fig. 7

given to the base of the tube and the variation of voltage across the plate circuit load is amplified and recorded on an oscillograph. The oscillographic records show the exact performance of the tube and form an excellent means of studying the problem of microphonic disturbance in tubes. The final form of the apparatus used for this test is indicated by the diagram of Fig. 2 and photograph of Fig. 3. The excitation is supplied by dropping a ball pendulum against the base of the tube which is mounted on a semi-rigid wood chamber. The tube is operated with a plate circuit load of 20,000 ohms impedance and

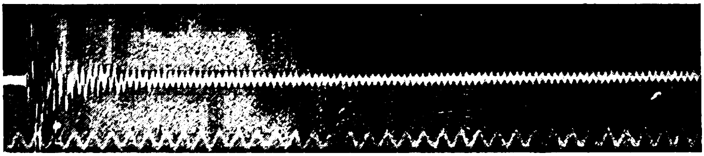

Fig. 8

the output disturbance amplified and placed on the oscillograph vibrator. Oscillograms are taken on standard motion picture film carried in a 200-ft. magazine in the film housing. In taking records the oscillograph driving motor is started by the same switch which releases the ball and one foot of film run off. A sixty-cycle timing wave is also placed on the film. Multiple impacts are prevented by attraction of the pendulum to a permanent magnet at one side of the socket.

Oscillograph impact records show the magnitude of initial microphonic response and the duration of the disturbances until the tube is

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again quiet. Both are important. Either or both may be the cause of disturbance in radio equipment, the actual voltage in the output circuit being a complex effect depending upon the character of the external disturbance. In addition the records indicate the principal frequency which is set up by such forced excitation of the tube elements. Typical oscillographic impact records are shown in Figs. 4 to

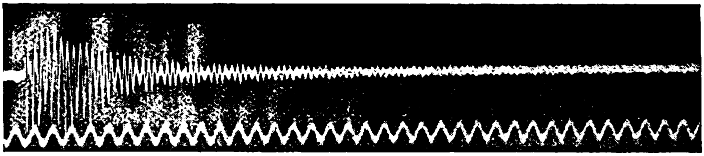

Fig. 9

14. Experience has shown that the records are entirely free from any major discrepancies between repeated tests or with impacts in different planes with respect to the tube elements.

Observation of the elements of the tube during the taking of the vibration frequency spectrum permits the determination of the

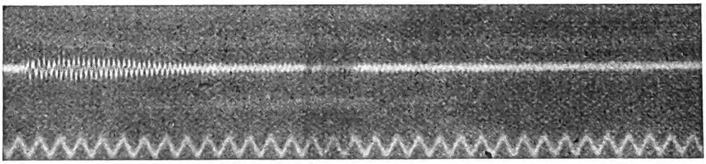

Fig. 10

principal sources of microphonic disturbances. Reference to Fig. 1 shows the multiplicity of resonance points within the tube itself. These points are usually sharply tuned. Any one of them may be sufficient to cause variation in plate current with a consequent ripple in the

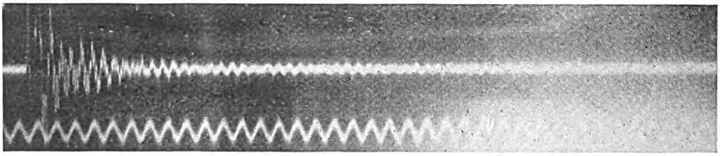

Fig. 11

output circuit when the tube is excited at the proper frequency. Likewise any freedom of motion may permit forced vibration when the whole tube is subject to a sudden impact of large magnitude. In this

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latter case the amount of microphonic ripple will be limited by the damping of the vibrating part.

In radio broadcast receivers where loud speaker feedback is the most serious microphonic defect the damping factor of the elements of the tube forms the limitation on microphonic output. If the amount of energy fed back is sufficient to overcome the loss by damping the effect will be to produce a sustained howl. In aircraft receivers on the other hand, where the vibrations of the various parts of the plane are

Fig. 12

transmitted to the tube, the effect is to force vibrations in the tube which are not of a transient nature and do not depend upon the damping factor in the same way. Stiffness of the electrode structure is important here.

The most common sources of trouble are filament vibration, mount[1] vibration, and grid vibration. The filament gives the most trouble because it is necessarily the freest part in the tube and can build up the largest amplitude. Filament vibration may be serious not only at its own natural period but also at that determined by the fila-

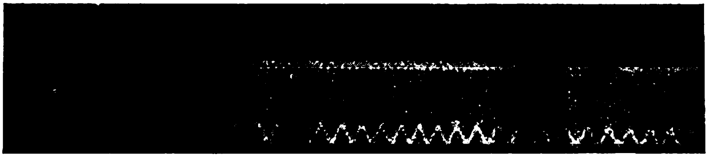

Fig. 13

ment and its supports taken together. Mount vibration gives trouble because of the vibration of the assembly of the tube elements at the natural period of the whole, permitting relative vibration of the various parts. Such vibration may also serve to force the filament into vibration at a frequency determined either by the period of the mount or by that of the filament. The grid vibration is important because of its large effect on the plate current. Its movement also may be sufficient

[1] The "mount" is the complete assembly of tube elements in place on the stem.

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to force vibration of the bead and consequently of the filament and other parts.

The great effect of the filament on tube noises is well shown by a series of oscillograms which have been taken on a group of tubes with amplification factors of approximately thirty. The tubes tested are indicated in Table I. The oscillograms as given were taken with the same impedance load (20,000 ohms at 60 cycles including a shunt resistor of 35,000 ohms to limit the impedance at higher frequencies)

TABLE I

STRUCTURE OF SPECIAL 30-μ TUBES

Oscillograms in Fig.	Filament Voltage	Filament Current (ampere)	Filament Shape	Filament Type	Plate	Remarks
4	3.3	0.06	Straight	Thoriated	Cylin.	Typical tube
5	3.3	0.06	Straight	Thoriated	Cylin.	Extra filament tension
6	5.0	0.25	V	Thoriated	Flat	Selected tube for special measurement work
7	5.0	0.25	V	Thoriated	Flat	Tube unsatisfactory as detector
8–9	1.5	1.0	V	Coated	Flat	Typical tubes
10	2.0	1.0	V	Coated	Flat	Specially reinforced elements
11–12	4.5	1.1	V	Thoriated	Flat	350-volt heavy duty tube
13–14	2.5	1.8	—	Cathode	Cylin.	

NOTE: Cylindrical plates were similar to UX199 with single side rod support. Flat plates were similar to UX201A or UX210 with double side rod.

and the same plate voltage. The difference in degree of disturbance is so great that it is readily shown up without attempting to adjust the amplifier gain to exactly the same for each tube. The oscillograms shown are made with a scale of 240 mv per cm.

These oscillograms show the improvement in initial disturbance and in time of decay as stiffness is obtained by the use of shorter and

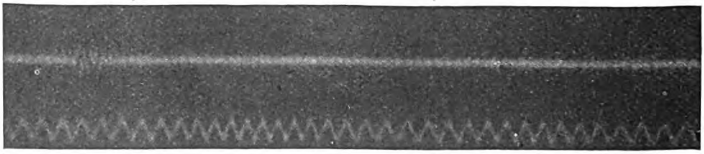

Fig. 14

heavier filaments. The 60-ma filament tubes (Figs. 4 and 5) show the filament disturbance resulting with the use of this light and low current filament. The five-volt V filament tubes show the extremes possible in this type of tube. High amplitudes such as in Fig. 7 may result from mounting of the filament so it is loose on the center hook. The

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best of these tubes are those of Figs. 8 and 9, which have large filaments such as are used for a-c filament operation. This is evident upon comparison with the tubes of Figs. 6 and 7, which are the same structure other than filaments. Small power tubes such as those in Figs. 11 and 12 are inherently freer from microphonic difficulties than the smaller tubes because of their heavier filaments and construction.

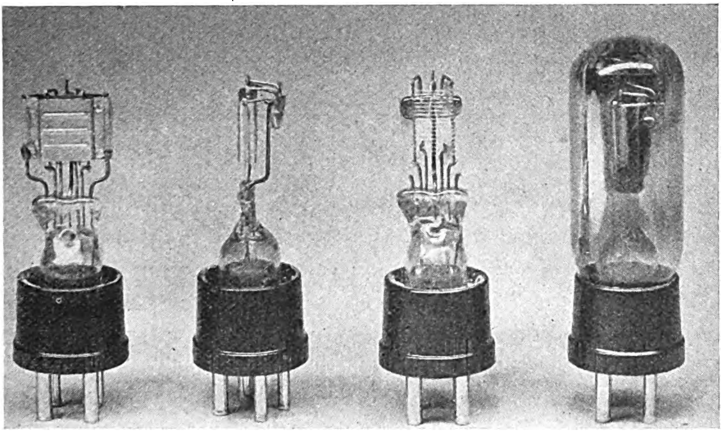

Fig. 15

One of the best solutions of the microphonic problem would be the use of such heavy filament tubes in receiving circuits, but such an arrangement is impractical because of the power requirements in most radio installations.

Experience has shown that an equipotential cathode tube such as the UY227 is the least subject to microphonic disturbances of any of the

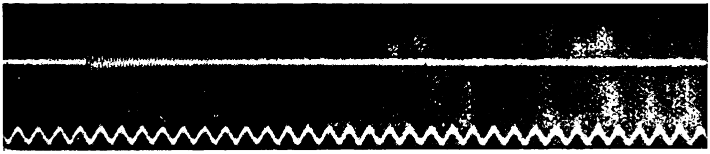

Fig. 16

small receiving tubes customarily used for detectors. The low amplitude of disturbance of such tubes is evident from the oscillograms of Figs. 13 and 14. The low microphonic response of the equipotential cathode tubes makes them particularly suitable for laboratory work where high gain amplification is required for measurement purposes.

The change in type of filament used will not change the micro-

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phonics of a given style of tube providing the same dimensions and weight of filament is used. In general, a coated wire will be heavier than a tungsten wire of the same filament rating, but the improvement to be obtained by change in the wire material is negligible as compared with that to be obtained by improvement of structure.

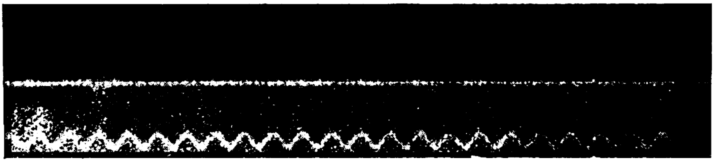

Fig. 17

As in many other design problems accentuation of one design factor can only be accomplished by some sacrifice of one or more other factors. Thus in a low microphonic tube low cost, gain per stage, and filament power may all be adversely affected in getting the desired freedom from tube noises traceable to mechanical vibration. For the

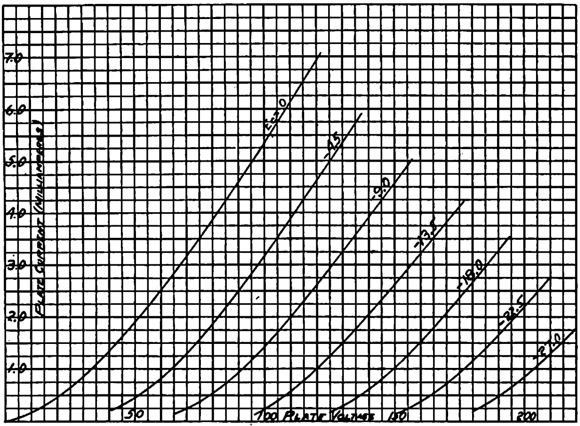

Fig. 18

great majority of applications freedom from the effects of vibration to the greatest extent is not justified because of this impairment in the other qualities of the tube.

A Low Microphonic Tube for Special Applications

A new vacuum tube which will not respond to external vibration has been developed for use where filament power is limited. This tube

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is Radiotron UX864,[2] the construction of which is indicated by the photograph of Fig. 15. Comparison of the oscillograms of Figs. 16 and 17 with the others previously given indicates the improvement obtained. Electrical characteristics and physical dimensions are given in Table II and a plate-voltage plate-current family in Fig. 18.

TABLE II
RADIOTRON UX864

Filament Voltage	1.1 volts
Filament Current	0.25 amperes
Plate Voltage	90 volts maximum
Average Characteristic Values at $Eb=90$ volts, $Ec=-4.5$ volts, $Ef=1.1$ volts	
Plate Current	2.5 milliamperes
Plate Resistance	15500 ohms
Mutual Conductance	425 micromhos
Amplification Factor	6.6
Plate-Grid Capacitance	5.2$\mu\mu$f
Maximum Over-all Dimensions	
Length	4 in.
Diameter	1 3/16 in.

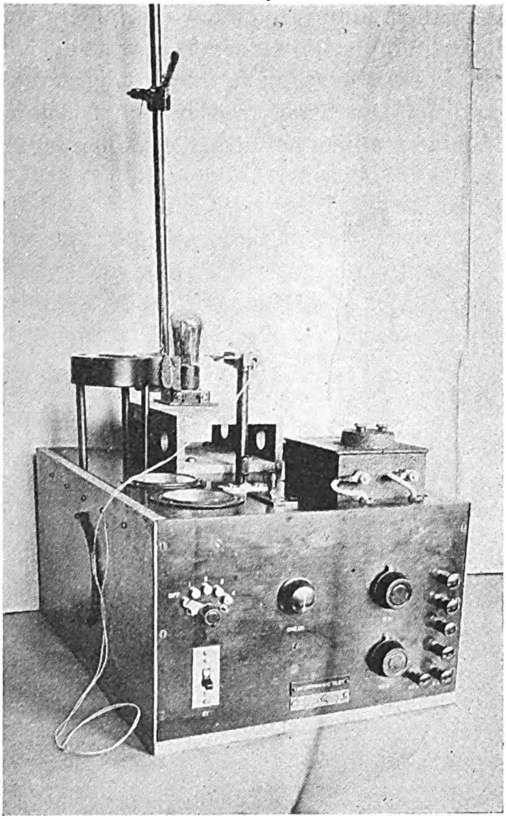

Fig. 19

[2] Jointly designed and produced by the General Electric and Westinghouse Companies for the Radio Corporation of America.

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Uniformity tests on microphonic response on a regular production of such tubes require a special apparatus because of the expense of taking individual oscillograms on each tube. An equipment for quantity testing is shown in Fig. 19. The same pendulum and mounting are used as before with the microphonic transient rectified and measured on a microammeter. The maximum deflection is proportional to the quantity of electricity represented in the transient wave. Since both high amplitude and poor damping are generally caused by looseness or weakness of parts a large deflection serves to indicate either or both defects. The amplifier is calibrated by discharging a condenser and subsequent charging through a high resistance grid leak.

The considerable activity in the field of aircraft receiver applications has caused a demand for an especially quiet tube which is being supplied by the UX864. Other applications include receivers and multi-stage tuned audio-frequency amplifiers on small motor driven boats where hull vibration is severe and studio condenser microphone amplifiers where the stand is frequently jarred during a performance. In addition it is being used in various commercial receiver equipments which are subject to either continuous vibration or momentary shocks.

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EQUIVALENT CIRCUITS OF AN ELECTRON TRIODE AND THE EQUIVALENT INPUT AND OUTPUT ADMITTANCES*

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Summary—*This paper is presented in two parts. In Part I two fundamental equivalence theorems concerning a triode and its circuits are rigorously derived. These theorems give the simple circuits which are equivalent to the plate and grid circuits of the triode. These equivalent circuits contain only constant circuit elements and fictitious electromotive forces, the use of which greatly simplifies the calculation of currents in the triode circuits when the electrical variations are small. In Part II the equivalence theorems are used to obtain the equivalent input and internal output admittances of a triode with its associated circuits.*

Part I

DEFINITIONS.[1] The instantaneous plate current i_p and the instantaneous grid current i_g through a triode are both uniquely determined by the instantaneous plate and grid potentials e_p and e_g, provided first, that the filament temperature remains constant, secondly, that the internal capacities of the tube are considered external to the tube so that the charging currents of these capacities are not included in i_p and i_g, and finally, provided that the time of flight of the electrons through the tube is negligible. The above stated in analytic form is

$$i_p = \psi(e_p, e_g)$$

$$i_g = \phi(e_p, e_g)$$

The total differentials of i_p and i_g are

$$di_p = \frac{\partial i_p}{\partial e_p} de_p + \frac{\partial i_p}{\partial e_g} de_g \tag{3}$$

$$di_g = \frac{\partial i_g}{\partial e_p} de_p + \frac{\partial i_g}{\partial e_g} de_g. \tag{4}$$

The four partial differential coefficients in (3) and (4) have the dimensions of conductances, and are given certain distinguishing names and

* Dewey decimal classification: R130. Original manuscript received by the Institute, March 21, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] The system of nomenclature used in this paper is that described by the author in a paper called "Vacuum-Tube Nomenclature," Proc. I.R.E., **15**, 181; March, 1927.

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letters as follows:

The first partial coefficient in (3) is called the incremental or variational plate conductance, and is denoted by the letter k_p. Hence

$$k_p = \left(\frac{\partial i_p}{\partial e_p}\right)_{e_g = \text{constant}}. \tag{5}$$

The second partial coefficient of (3) concerns two circuits and, for want of a better term, is known as the incremental or variational mutual conductance and is denoted by the Greek letter σ_p. Hence

$$\sigma_p = \left(\frac{\partial i_p}{\partial e_g}\right)_{e_p = \text{constant}}. \tag{6}$$

It should be noted here that while the quantity defined in (6) expresses the change in plate current due to a change in grid voltage, there is no equal reverse effect implied by the term mutual.

The first partial coefficient of (4) is intrinsically a negative quantity under most normal conditions, and hence the coefficient with a negative sign is defined as the incremental or variational inverse mutual conductance and is denoted by the letter σ_g.

$$\sigma_g = -\left(\frac{\partial i_g}{\partial e_p}\right)_{e_g = \text{constant}}. \tag{7}$$

The comment in the previous paragraph regarding the use of the word mutual is also applicable here.

Finally, the second partial coefficient in (4) is called the incremental or variational grid conductance and is denoted by the letter k_g. Hence

$$k_g = \left(\frac{\partial i_g}{\partial e_g}\right)_{e_p = \text{constant}}. \tag{8}$$

Equations (3) and (4) can now be written

$$di_p = k_p de_p + \sigma_p de_g \tag{9}$$

$$di_g = -\sigma_g de_p + k_g de_g. \tag{10}$$

If we suppose that e_p and e_g vary so that i_p remains constant, then (9) becomes

$$k_p de_p + \sigma_p de_g = 0. \tag{11}$$

The ratio de_p/de_g, which under the assumed conditions is a partial differential coefficient with i_p constant, has from (11) the value

$$\frac{\sigma_p}{k_p} = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_p = \text{constant}}. \tag{12}$$

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The quantity on the right hand side of (12) is called the incremental or variational amplification factor and is denoted by the Greek letter μ_p. Then

$$\mu_p = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_p = \text{constant}} \tag{13}$$

and from (12) the three partial coefficients are related as shown below:

$$\sigma_p = \mu_p k_p. \tag{14}$$

Similarly we may assume that e_g and e_p vary so that i_g remains constant. By placing di_g equal to zero in (10) we obtain

$$\frac{\sigma_g}{k_g} = \left(\frac{\partial e_g}{\partial e_p}\right)_{i_g = \text{constant}}. \tag{15}$$

The partial coefficient on the right side of (15) is defined as the incremental or variational inverse factor and is denoted by the Greek letter μ_g.* Hence

$$\mu_g = \left(\frac{\partial e_g}{\partial e_p}\right)_{i_g = \text{constant}}. \tag{16}$$

and from (15) we have

$$\sigma_g = \mu_g k_g. \tag{17}$$

One additional coefficient is of value and will now be defined. The total space charge current from the filament is equal to the sum of the grid and plate currents, or

$$i_s = i_g + i_p. \tag{18}$$

Now i_s is also a function of e_p and e_g expressed in the form

$$i_s = f(e_p, e_g). \tag{19}$$

The total differential of i_s is obtained by adding (9) and (10) and is

$$di_s = (k_p - \sigma_g)de_p + (\sigma_p + k_g)de_g. \tag{20}$$

Now, if we define μ_s as the negative of the ratio of the increment in plate voltage to the increment in grid voltage to maintan i_s constant, i.e.

$$\mu_s = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_s = \text{constant}}. \tag{21}$$

* μ_g as defined here is the negative of ν defined by Llewellyn and called by him the reflex factor. F. B. Llewellyn, "Operation of Thermionic Vacuum Tube Circuits," *Bell Tel. Lab.*, August, 1926. Reprint B-20.

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we have from (20), putting di_s equal to zero,

$$\mu_s = \frac{\sigma_p + k_g}{k_p - \sigma_g}\,. \tag{22}$$

Relation (22) is of value because, although all of the coefficients defined in (5), (6), (7), (8), (13), and (16) vary considerably over the working ranges of plate and grid voltages, μ_s is practically constant and is equal to the ratio of plate voltage to the grid voltage, which two voltages, if acting singly, produce the same electrostatic field at the filament. The quantity μ_s depends then mostly upon the geometry of the tube and only slightly upon the space charge so long as the space charge is near the filament. The constancy of μ_s is shown by Fig. 1,

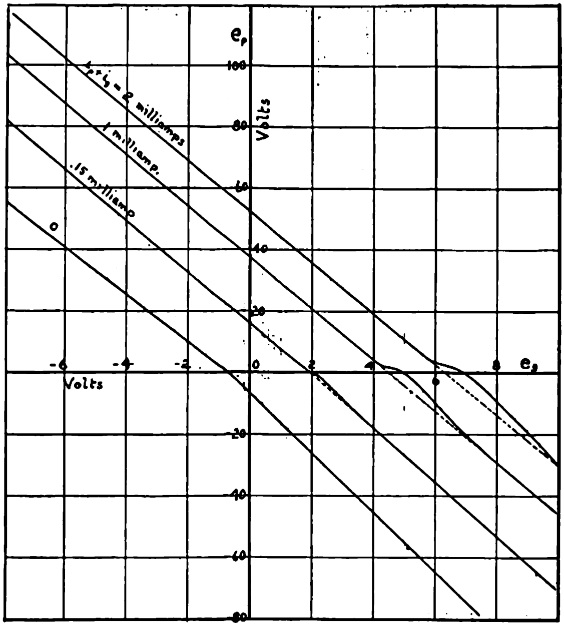

Fig. 1

which is a plot of constant i_s for a standard type low-power triode commonly used as an amplifier. It will be noted that μ_s, which is the slope of the curves of Fig. 1, deviates from its normal constant value only when e_p is near zero. Under this condition the electrons are attracted by the grid, but some pass through the meshes and because of the retarding field between the grid and plate are turned back toward the grid. These electrons may travel many times around the grid wires before finally entering the grid, thus producing a considerable

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space charge around the grid. This space charge alters the relative effects of the plate and grid voltages in producing a field at the filament and hence changes the value of μ_s.

It is obvious that over the range where μ_s is constant i_s can be expressed by a more specific relation than (19), i.e.

$$i_s = f(e_p + \mu_s e_g). \tag{23}$$

The definitions of the seven coefficients given above are made so that the coefficients are positive quantities under ordinary operating conditions for a high-vacuum triode.

Equivalent Plate-Circuit Theorem.[2] Fig. 2 shows a triode with impedances Z_c and Z_b in the grid and plate circuits, respectively. The instantaneous values of the currents and electromotive forces are defined by the figure. The steady polarizing potentials in the grid

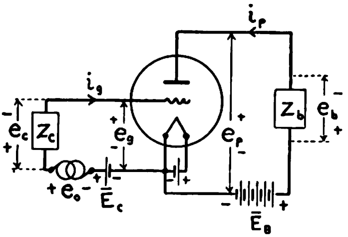

Fig. 2

and plate circuits are $\bar{E}_C$ and $\bar{E}_B$, respectively. There will be certain steady components of the grid and plate potentials designated by $\bar{E}_g$ and $\bar{E}_p$, respectively, and certain steady components of the grid and plate currents designated by $\bar{I}_g$ and $\bar{I}_p$, respectively.

Fig. 3 is the $i_p - e_p$ diagram for the triode, and if there is no varying potential impressed in the grid circuit, the operating point Q is determined by the steady components of the grid and plate potentials. Point Q is called the *quiescent* or *Q-point*.

If now the grid voltage changes by a small amount de_g, the operating point will move to some new position A, and (9) gives the relation

[2] This theorem has long been known and commonly used, but the author has been unable to find a simple but rigorous derivation. The first reference to this theorem which the author has found is in an article by J. M. Miller, Proc. I.R.E., 6, 143; June, 1918. There, in a footnote, Miller states that the theorem was suggested to him by H. H. Beltz of the Bureau of Standards.

The theorem may appear to follow axiomatically from the definition of μ_p but the author believes that some may be helped if the elementary steps in the reasoning are supplied.

See "Theory and Operating Characteristics of the Thermionic Amplifier," by van der Bijl, Proc. I.R.E., 7, 97; April, 1919, and "A Theoretical Study of the Three-Element Vacuum Tube," John R. Carson Proc. I.R.E., 7, 187; April, 1919.

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between the change of plate current and the changes of grid and plate potentials.

Since $\overline{E}_B$ is constant, then $de_p = -de_b$ and (9) can be rewritten combining at the same time with (14)

$$di_p = k_p(\mu_p de_g - de_b). \tag{24}$$

We may now define r_p, the variational plate resistance, as the reciprocal of k_p, and then (24) becomes

$$r_p di_p + de_b = \mu_p de_g. \tag{25}$$

Usually e_g varies with time in a predetermined manner so that by dividing by dt we have the following fundamental differential equation for the triode:

$$r_p \frac{di_p}{dt} + \frac{de_b}{dt} = \mu_p \frac{de_g}{dt}. \tag{26}$$

In deriving the above equations the origin of coordinates was at O of Fig. 3. Since we may be interested only in changes of current and potentials, we may transfer the origin of coordinates to Q and consider small but finite changes from the point Q, the changes being always

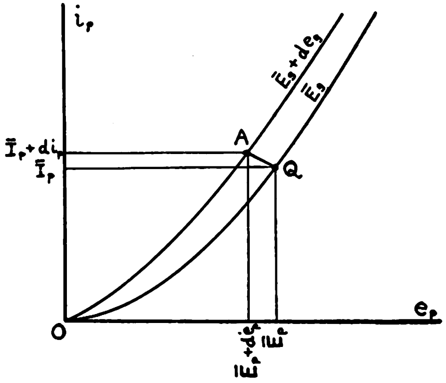

Fig. 3

so small that r_p and μ_p are essentially constant over the path travelled by the operating point. Then we may rewrite (25) in the form

$$r_p \Delta i_p + \Delta e_b = \mu_p \Delta e_g. \tag{27}$$

Equation (27) is one form of the equivalent plate-circuit theorem. According to (27) *the small plate current measured from the Q-point can be calculated assuming an equivalent circuit containing a resistance*

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r_p, an impedance or combination of circuit elements Z_b, and a fictitious voltage $\mu_p \Delta e_g$.

If the nature of Z_b is known, then Δe_b can be expressed in terms of the current Δi_p. For example, suppose that Z_b consists of an inductance L_b and resistance R_b in series. Then $\Delta e_b = L_b\, d(\Delta i_p)/dt + R_b \Delta i_p$ and (27) can be written

$$L_b \frac{d(\Delta i_p)}{dt} + (r_p + R_b)\Delta i_p = \mu_p \Delta e_g. \tag{28}$$

If Δe_g is a discontinuous change with respect to time, then (28) gives the transient change in Δi_p. If Δe_g is a sinusoidal emf having an r.m.s. value of ΔE_g, then the r.m.s. value of the plate current measured from Q is

$$\Delta I_p = \frac{\mu_p \Delta \mathbf{E}_g}{r_p + \mathbf{Z}_b} \tag{29}$$

where bold-faced type denotes complex quantities. Equation (29) is the statement of the theorem for sinusoidal currents and potentials.

Equivalent Grid-Circuit Theorem.[3]—The derivation of the equivalent grid circuit theorem is exactly similar to the above derivation and will therefore be but briefly outlined. Equations (10) and (17) combine giving

$$di_g = k_g(de_g - \mu_g de_p). \tag{30}$$

Now adding emf's in the grid circuit of Fig. 2 we have

$$e_0 - e_c - e_g + \overline{E}_c = 0 \tag{31}$$

or

$$de_g = de_0 - de_c \tag{32}$$

where e_0 is an impressed emf from an outside source. Combining (32) and (30), at the same time using r_g as the reciprocal of k_g, we have

$$r_g di_g + de_c = de_0 - \mu_g de_p. \tag{33}$$

The companion differential equation of (26) is obtained by dividing (33) by dt.

As before we may change the origin of coordinates to the grid quiescent point and write (33)

$$r_g \Delta i_g + \Delta e_c = \Delta e_0 - \mu_g \Delta e_p. \tag{34}$$

[3] The author has been unable to find any derivation or statement of the equivalent grid-circuit theorem. van der Bijl, in his book, "Thermionic Vacuum Tubes," 1920, on page 187 gives the equivalent of equation (10). Latour in *Electrician*, December, 1916, also derives equation (10).

Llewellyn (loc. cit.) takes fully into account the reaction of the plate voltage upon the grid circuit, but does not derive or state this theorem.

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According to (34), one form of the equivalent grid-circuit theorem, *the small grid current measured from the quiescent point can be calculated assuming an equivalent grid circuit containing a resistance r_g, an impedance or combination of circuit elements Z_c, and an impressed emf of Δe_0 minus a fictitious voltage of $\mu_g \Delta e_p$.*

As in the former theorem transient changes measured from the quiescent point can be calculated, or if the impressed emf Δe_0 is sinusoidal, then the small alternating component of grid current can be obtained from the complex expression

$$\Delta I_g = \frac{\Delta E_0 - \mu_g \Delta E_p}{r_g + Z_c}. \tag{35}$$

Equation (35) is a statement of the equivalent grid-circuit theorem for alternating currents and potentials.

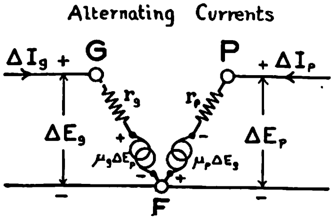

Fig. 4

Fig. 4 gives the equivalent internal circuits of a triode when the tube capacities are neglected. The points G, P, and F correspond, respectively, to the grid, plate, and filament terminals. The terminology on Fig. 4 is given for alternating variations, but the same figure can be used as a model for the calculation of transient changes.

Part II[4]

Equivalent Input Admittance of a Triode. In this part the effects of tube capacities are taken fully into account in the calculation of the input and output admittances of a triode. The complete equivalent network of a triode and its circuits is shown in Fig. 5. The three capacities of the tube and its socket are represented by C_g, C_m, and C_p. For simplicity in the analysis the plate-to-filament capacity C_p will be considered a part of the plate load. The admittance of the combination

[4] The equivalent input impedance of the triode, neglecting the effect of $\mu_g \Delta E_p$ was derived by J. M. Miller in 1919 (see Bureau of Standards, Bulletin No. 351), by Stuart Ballantine in 1920 (see *Phys. Rev.*, **15**, No. 5, p. 409), and by H. W. Nichols in 1919 (see *Phys. Rev.*, **13**, p. 405).

The equivalent internal output admittance or impedance has not been derived so far as the author knows.

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is denoted by Y_b' where $Y_b'=Y_b+jC_p\omega$. Similarly C_g is considered a part of the grid circuit admittance $Y_c'=Y_c+jC_g\omega$. The final result is, however, expressed not in terms of Y_b' and Y_c' but in terms of their component parts.

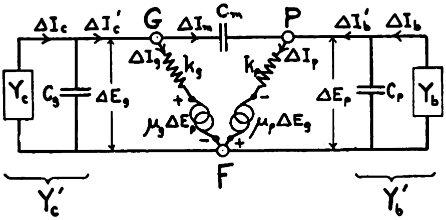

Fig. 5

The actual input admittance of the triode is

$$y_g=\frac{\Delta I_c}{\Delta E_g}=\frac{\Delta I_c'}{\Delta E_g}+jC_g\omega.\ ^{5}$$

The admittance $\Delta I_c'/\Delta E_g$ is obtained by solving the following equations for the network of Fig. 5.

$$\left.\begin{aligned}
-\Delta I_m+\Delta I_c'-\Delta I_g&=0\\
+\Delta I_m+\Delta I_b'-\Delta I_p&=0\\
\sigma_g\Delta E_p+\Delta I_g&=k_g\Delta E_g\\
-k_p\Delta E_p+\Delta I_p&=\sigma_p\Delta E_g\\
+\Delta I_m+jC_m\omega\Delta E_p&=jC_m\omega\Delta E_g\\
+\Delta I_b'+Y_b'\Delta E_p&=0
\end{aligned}\right\}\quad(40)$$

Attention is called to the fact that the admittance between grid and plate is here assumed to consist only of a capacity. If conductance also exists between these terminals or in general if the admittance is Y_m, then Y_m should be substituted for jC_mw in the fifth equation in group (40). The simple case has been carried through in this paper because of the algebraic complexity of the general solution.

The input admittance derived from the above relation is

$$y_g=\left\{k_g+\frac{(\sigma_p\sigma_g+C_m^2\omega^2)(k_p+G_b)+C_m\omega(\sigma_p-\sigma_g)\left[(C_m+C_p)\omega-B_b\right]}{[k_p+G_b]^2+[(C_m+C_p)\omega-B_b]^2}\right\}$$

$$+j\left\{(C_g+C_m)\omega\right.$$

[5] A small letter is used for y_g because the input admittance is a function of the plate and grid polarizing potentials. See reference 1.

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$$+\left.\frac{C_m\omega(\sigma_p-\sigma_g)(k_p+G_b)-(\sigma_p\sigma_g+C_m{}^2\omega^2)\left[(C_m+C)\omega-B_b\right]}{[k_p+G_b]^2+[(C_m+C_p)\omega-B_b]^2}\right\} \quad (41)$$

Equivalent Internal Output Admittance. Because of the symmetry of the network of Fig. 5, the equivalent internal output admittance, or $y_p=\Delta I_b/\Delta E_p$ can be obtained from (41) by changing all p subscripts to g, and vice versa, and subscript b to c, and also reversing the signs of σ_p and σ_g.

$$y_p=\left\{k_p+\frac{(\sigma_p\sigma_g+C_m{}^2\omega^2)(k_g+G_c)+C_m\omega(\sigma_p-\sigma_g)\left[(C_m+C_g)\omega-B_c\right]}{[k_g+G_c]^2+[(C_m+C_g)\omega-B_c]^2}\right\}$$

$$+j\left\{(C_p+C_m)\omega\right.$$

$$+\left.\frac{C_m\omega(\sigma_p-\sigma_g)(k_g+G_c)-(\sigma_p\sigma_g+C_m{}^2\omega^2)\left[(C_m+C_g)\omega-B_c\right]}{[k_g+G_c]^2+[(C_m+C_g)\omega-B_c]^2}\right\} \quad (42)$$

The magnitudes of y_g and y_p depend upon the four tube coefficients k_p, k_g, σ_p and σ_g, all of which are functions of the plate and grid potentials. Since μ_s (23) is practically a constant for any given tube except for very low values of E_p, equation (23) can be used to eliminate σ_g from (41) and (42), making y_g and y_p functions of the variable factors k_p, k_g, and σ_p or μ_p.

Special Cases of y_g and y_p

Case 1. Input Admittance for $k_g=0$, $B_b=0$

This case applied to an amplifier whose grid is polarized negatively and whose plate load is a pure resistance. Equation (41), giving the equivalent input admittance, reduces to the following form on putting $k_g=0$ and $B_b=0$.

$$\sigma_g=0,\ B_b=0 \quad \left\{ \begin{aligned} \frac{g_g}{k_p}&=A^2\frac{\left(1+\dfrac{1}{x_b}\right)+\mu_p\left(1+\dfrac{C_p}{C_m}\right)}{\left(1+\dfrac{1}{x_b}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}\right)^2} && (43)\\ \frac{b_g}{k_p}&=-A\left[1+\frac{C_g}{C_m}+\frac{\mu_p\left(1+\dfrac{1}{x_b}\right)-A^2\left(1+\dfrac{C_p}{C_m}\right)}{\left(1+\dfrac{1}{x_b}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}\right)^2}\right] && (44) \end{aligned}\right.$$

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where $y_g = g_g - jb_g$; $x_b = R_b/r_p$; and $A = C_m\omega/k_p$. The expressions for the input and output admittances are much simpler of interpretation when expressed in ratio form. By dividing through by k_p, the equivalent conductance and susceptance divided by k_p are then functions of the simple ratios R_b/r_p, $C_m\omega/k_p$, μ_p, C_p/C_m and C_g/C_m. The last two ratios are constants and μ_p is nearly constant for any given tube.

In Fig. 6 are plotted g_g/k_p and b_g/k_p against $R_b/r_p = x_b$ as abscissas for various values of the parameter A. The values of μ_p, C_p/C_m, and C_g/C_m used in the calculations correspond approximately to a standard 201A tube, for which μ_p is 8 and the values of C_m, C_p, and C_g, including the capacities of the socket are taken as 10, 5, and 5$\mu\mu$f, respectively. The parameter A has the value unity if r_p is 16,000 ohms and the frequency is 10^6 cycles per second.

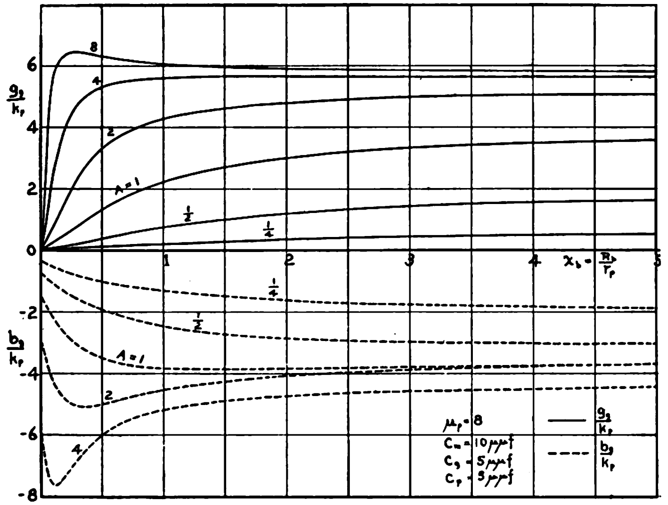

Fig. 6

Examination of Fig. 6 shows that when the plate load of an amplifier is a pure resistance or the equivalent the triode acts upon the input circuit as though there were connected from the grid to filament a resistance and capacity in parallel, both the resistance and the capacity reactance may be much less than r_p, especially if the frequency is high.

Case 2. Internal Output Admittance for $k_g = 0$ and $B_c = 0$

This case applies to an amplifier whose grid is polarized negatively and whose grid circuit contains a pure resistance. Equation (42) reduces to the following expression when $k_g = 0$ and $B_c = 0$.

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$$k_g=0,\quad B_c=0\quad \begin{cases} \dfrac{g_p}{k_p}=1+A^2\dfrac{\dfrac{1}{x_c}+\mu_p\left(1+\dfrac{C_g}{C_m}\right)}{\left(\dfrac{1}{x_c}\right)^2+A^2\left(1+\dfrac{C_g}{C_m}\right)^2} & (45)\\[2ex] \dfrac{b_p}{k_p}=-A\left[1+\dfrac{C_p}{C_m}+\dfrac{\dfrac{\mu_p}{x_c}-A^2\left(1+\dfrac{C_g}{C_m}\right)}{\left(\dfrac{1}{x_c}\right)^2+A^2\left(1+\dfrac{C_g}{C_m}\right)^2}\right] & (46)\end{cases}$$

where $y_p=g_p-jb_p$, $x_c=R_c/r_p$ and $A=C_m\omega/k_p$.

Fig. 7 illustrates the shape of the curves obtained by plotting (45) and (46) against R_c/r_p as abscissas for a 201A tube having the same constants as in Case 1.

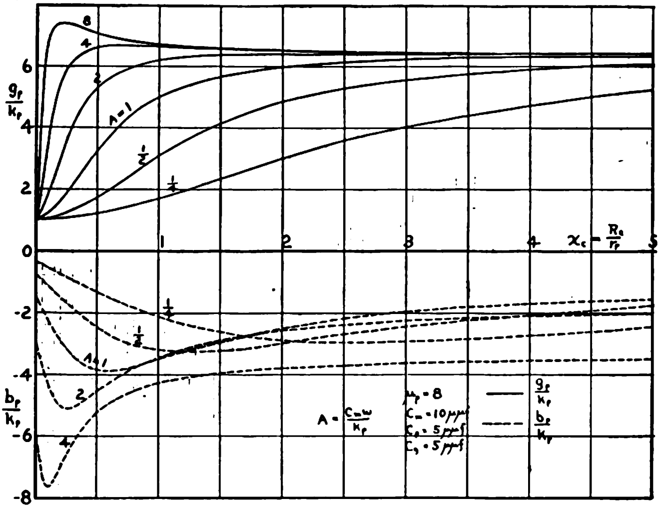

Fig. 7

Looking back into the triode from the plate load, the triode with its associate grid load of a pure resistance is equivalent to a resistance and capacity in parallel. Both resistance and reactance may be much less than r_p as shown by the curves of Fig. 7.

Case 3. Input Admittance for Reactive Plate Load, $k_g=0$.

This third case applies to an amplifier whose grid is polarized negatively and whose plate load has both resistance and reactance. Another parameter η_b is now introduced, its absolute value giving the ratio of the conductance to the susceptance of the load, or $\eta_b=G_b/|B_b|$. Equation

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(41) is then reduced for this case by substituting for G_b the quantity $\eta_b |B_b|$ and putting $k_g=0$. The result is as follows:

$$k_g=0 \quad \begin{cases} \dfrac{g_g}{k_p}=A^2\dfrac{1+\dfrac{\eta_b}{|x_b'|}+\mu_p\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)}{\left(1+\dfrac{\eta_b}{|x_b'|}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)^2} & (47) \\[2ex] \dfrac{b_g}{k_p}=-A\left[1+\dfrac{C_g}{C_m}+\dfrac{\mu_p\left(1+\dfrac{\eta_b}{|x_b'|}\right)-A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)}{\left(1+\dfrac{\eta_b}{|x_b'|}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)^2}\right] & (48) \end{cases}$$

where $y_g=g_g-jb_g$; $x_b'=k_p/B_b$ and $A=C_m\omega/k_p$. The coordinate x_b' is positive if the load is inductive and negative if the load is capacitive.

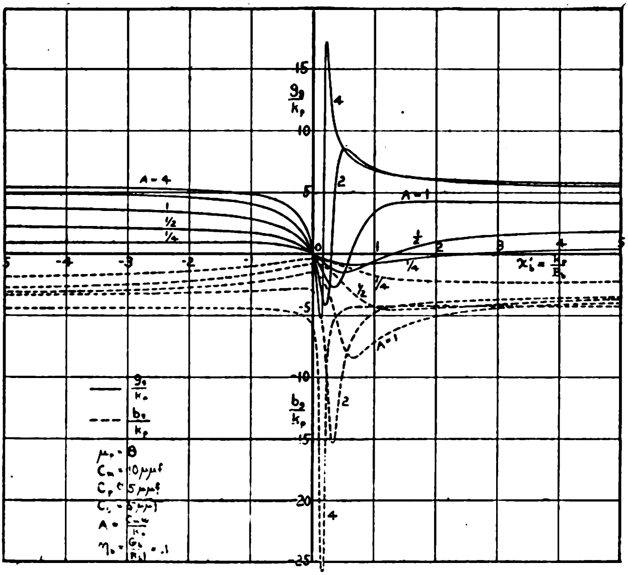

Fig. 8

In Fig. 8 expressions (47) and (48) are plotted for η_b equal to 0.1 and for several values of A. The values of μ_p, C_p, C_m, and C_g are the same as in Case 1 and correspond to those of a 201A tube.

In Fig. 9 expressions (47) and (48) are plotted for $A=1$ and for several values of η_b. The constants of the tube are as in Fig. 8.

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Referring now to Figs. 8 and 9 it is seen that the susceptance of the input admittance is always capacitive no matter what may be the type of plate load. The input conductance is positive for all plate loads which have a capacitive susceptance, but the input conductance is negative for plate loads having certain ranges of inductive susceptance.

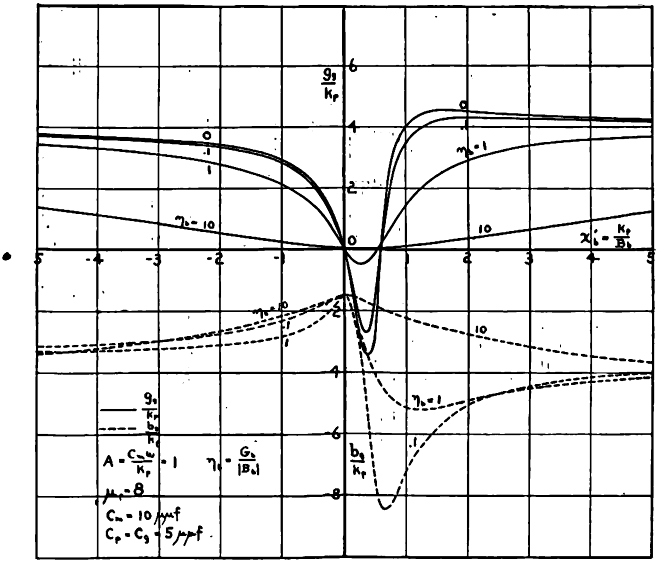

Fig. 9

The triode and its plate load may, so far as effects in Y_c are concerned, be replaced by its equivalent input admittance y_g in parallel with Y_c. It can easily be shown that the system will oscillate if $Y_c+y_g=0$ or oscillation will occur if the grid circuit contains an inductance and capacity in parallel where $R_c/(R_c^2+L_c^2\omega^2)+g_g\leqq 0$ and if

$$C_c\omega-\frac{L_c\omega}{R_c^2+L_c^2\omega^2}-b_g=0.$$

Case 4. Internal Output Admittance for Reactive Grid Circuit. $k_g=0$

This case applies to the internal output admittance of an amplifier tube whose grid is polarized negatively and whose grid circuit contains both resistance and reactance, the latter being either inductive or capacitive. As in Case 3 a new parameter $\eta_c=G_c/|B_c|$ is introduced. Formula (42) reduces to the following form:

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$$
k_g = 0 \left\{
\begin{aligned}
\frac{g_p}{k_p} &= 1 + A^2 \frac{\dfrac{\eta_c}{|x_c'|} + \mu_p\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)}{\left(\dfrac{\eta_c}{x_c'}\right)^2 + A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)^2} && (49) \\
\frac{b_p}{k_p} &= -A\left[1 + \frac{C_p}{C_m} + \frac{\dfrac{\mu_p \eta_c}{|x_c'|} - A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)}{\left(\dfrac{\eta_c}{x_c'}\right)^2 + A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)^2}\right] && (50)
\end{aligned}
\right.
$$

where $y_p = g_p - jb_p$, $x_c' = k_p/B_c$ and $A = C_m\omega/k_p$.

In Fig. 10 expressions (49) and (50) are plotted for η_c equal to 0.1 and for several values of A. The values of μ_p, C_p, C_m, and C_g are the same as in Case 1 and correspond to those of a 201A tube.

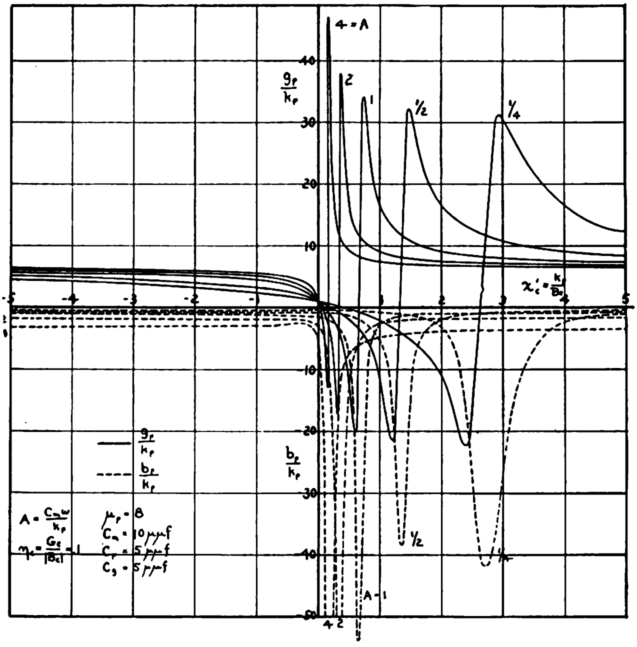

Fig. 10

In Fig. 11 expressions (49) and (50) are plotted for A equal to 1 and for several values of η_c.

The results in this case are analogous to those of Case 3 in that the equivalent output susceptance like the input susceptance is always capacitive. Further, the output conductance is positive if the grid circuit has a capacitive susceptance, but may be negative if the grid

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circuit is inductive. The conditions of oscillation are expressed by the relation $Y_b + y_p = 0$ or $R_b/(R_b^2 + L_b^2\omega^2) + g_p \leqq 0$ and

$$C_b\omega - \frac{L_b\omega}{R_b^2 + L_b^2\omega^2} - b_p = 0.$$

Case 5. Input and Output Admittance for $\sigma_g \neq 0$ and $\omega = 0$.

In all of the first four cases the grid was assumed to be polarized negatively so that k_g was equal to zero. A detector is, however, often

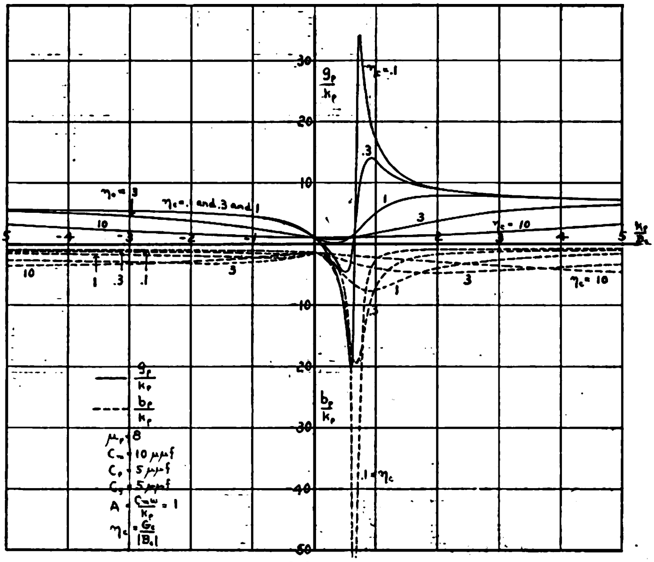

Fig. 11

operated so that the grid is slightly positively polarized. In this case k_g is not zero, and the terms containing σ_g and k_g in (41) and (42) must be considered. The formulas are then much more complicated. These expressions will be given assuming the frequency is very low.

$$\frac{g_g}{k_g} = 1 + \frac{\mu_p \mu_g}{1 + \dfrac{G_b}{k_p}} \qquad (51)$$

$$\frac{g_p}{k_p} = 1 + \frac{\mu_p \mu_g}{1 + \dfrac{G_c}{k_g}}. \qquad (52)$$

Expressions (51) and (52) show that if μ_g is positive as it usually is for a high-vacuum tube, the input and output conductances are increased as the grid is made more positive. On the other hand, μ_g may be negative if gas is present in a triode, so that the input and output conductances may be decreased and even become negative.

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AN INVESTIGATION OF THE PHENOMENA OF FREQUENCY MULTIPLICATION AS USED IN TUBE TRANSMITTERS*

By

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Summary—*A commonly used method is described for obtaining crystal control of high-frequency transmitters from crystals of lower frequency by means of a frequency multiplying vacuum-tube amplifier. An experimental study of the operation of the system is made when doubling and tripling the frequency of a 4000-kc crystal-controlled oscillator, and comparisons are made with the operation of the same system when balanced and amplifying the fundamental frequency.*

Relations between d-c negative grid voltage and r-f input voltage for maximum efficiency are shown to be critical and nearly constant for any one order of multiplication. Satisfactory operation of the system is shown to depend upon inductive reactance in the grid circuit, which produces regeneration through the grid-plate feed back in the tube.

The study is based on circuit efficiencies as measured by the contact pyrometer method.

IT is known that a self oscillating vacuum-tube circuit does not maintain a constant frequency over a period of time. The use of oscillating quartz crystals for stabilizing the frequency of transmitters is common practice. Crystal control is useful in the intermediate frequency band from 300 to 10,000 kc for preventing interference between stations operating on adjacent frequencies. It is imperative in the high frequencies from 10,000 to 30,000 kc for keeping the beat note in receivers from changing beyond the limits of audibility due to small variations in transmitter frequency. The following example illustrates this point:

In receiving continuous wave signals with an oscillating detector, a change in beat note of 100 cycles occurs with a variation of 0.2 per cent in the frequency of a transmitter operating on 500 kc. If the transmitter were operating on 25,000 kc a variation of only 0.004 per cent in the transmitted frequency would produce the same change in the received beat note. It is therefore evident that the practical value of high-frequency transmitters rests in the possibility of maintaining their frequencies at extremely constant values.

The use of piezo-electric crystals for frequency stabilization has certain limitations. Inasmuch as the frequency of a crystal of a given nature is roughly determined by the physical dimensions of that crystal, there is obviously a limit to the frequencies which can be pro-

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duced by this means. As a large crystal gives a lower frequency than a small crystal of the same nature, the lower frequency limit is fixed by the maximum size obtainable in such crystals. On the other hand, when a crystal is ground small for high frequencies it becomes fragile and, in the limit, breaks under the strain of oscillation. The maximum practical range for power crystals is about 25 to 6,000 kc. This range is far below the high frequencies where crystal control is almost indispensable.

For obtaining crystal control of high-frequency transmitters an ingenious frequency multiplying system was developed several years ago at the Naval Research Laboratory.[1] The system consists of a crystal-controlled vacuum-tube circuit oscillating on the crystal frequency, and a non-oscillating power amplifier tuned to a small integral multiple of the crystal frequency. The oscillatory current in the output circuit is on the higher frequency, to which it is tuned. This frequency multiplying amplifier is operated with a very high d-c blocking voltage on the grid and a correspondingly high radio-frequency voltage excitation from the oscillator. The output is nearly 100 per cent on the multiple frequency which is positively controlled by the crystal oscillator.

Shortly after this system was adopted a theoretical analysis of its operation was undertaken.[2] In this analysis the order of multiplication was expressed as a function of the period of time of plate current flow in terms of the period of the input voltage. The assumption was made that plate current would flow only during the positive half of one cycle of output current for each cycle of input voltage. If the period of input voltage be taken as unity, the period of flow of plate current would be one-fourth for doubling, one-sixth for tripling, etc. During the remaining three-fourths or five-sixths of the time the oscillatory current in the output circuit must maintain itself solely by its own inertia. The condition is illustrated in Fig. 1.

It has also been believed that the feed-back through the grid-plate capacity of the tube from the output to the input circuits must always have a damping effect on the input voltage and so limit the output and efficiency of the amplifier to low values. With this in mind a screened grid tube, which has a very low effective grid-plate capacity, was used in place of the three-electrode tube previously used. A reduction in both output and efficiency was the surprising result.

[1] Developed and patented by A. Hoyt Taylor and L. C. Young.
[2] Report filed at Naval Research Laboratory by Edwin L. White, now with the Army at Fort Shaster, Hawaii.

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An investigation has recently been made to study the operation of this circuit and offer some explanation of the noted phenomena. A quarter kw transmitter was built for the purpose, with a 100-watt push-pull master oscillator crystal controlled in the 4000-kc band, and a frequency multiplying amplifier utilizing a single 250-watt tube.

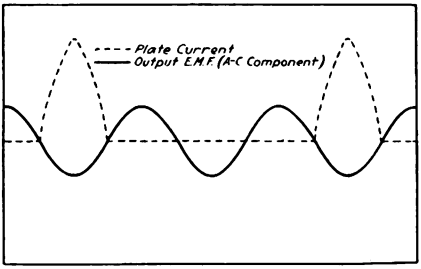

Fig. 1

Both circuits were tuned plate parallel feed, with capacitive coupling between oscillator output and amplifier input. The circuit diagram is shown in Fig. 2.

The efficiency and output of the amplifier was measured by the surface pyrometer method, in which the power dissipated in the tube is ascertained by the temperature of the glass wall of the tube.[3]

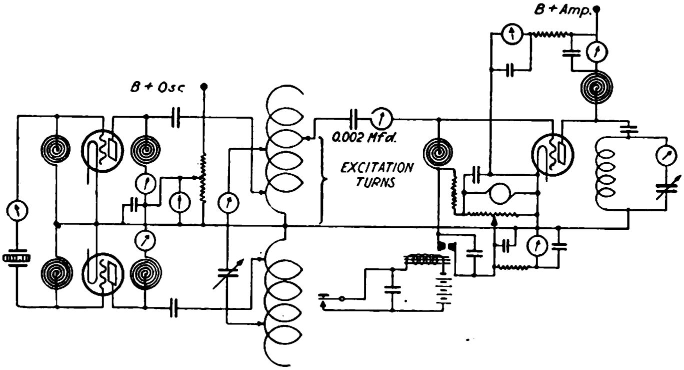

Fig. 2

The radio-frequency input voltage to the amplifier, hereafter referred to as the excitation voltage, was measured by using the amplifier temporarily as a blocked-grid vacuum-tube voltmeter. This method gives positive peak values when no load is being taken from the oscillator. When power is taken from the oscillator to operate the ampli-

[3] A. Crossley and R. M. Page, "A New Method for Determining the Efficiency of Vacuum-Tube Circuits," Proc. I. R. E., 16, 1375; October, 1928.

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fier, the output voltage of the oscillator is reduced. Some means was therefore necessary for maintaining a constant excitation voltage while other factors in the amplifier were varied. An attempt was made to accomplish this by adjusting the d-c plate voltage on the oscillator tubes to keep a constant r-f current in the oscillator tank circuit. Under this condition, constant effective voltage excitation was assumed.

The d-c plate voltage on the amplifier was kept constant at all times. Output was varied by adjusting negative bias on the grid or by changing excitation voltage. The following paragraphs give a resumé of the findings made in this study.

It was found that for any given excitation voltage there is a fairly critical adjustment of negative "C" voltage for maximum efficiency

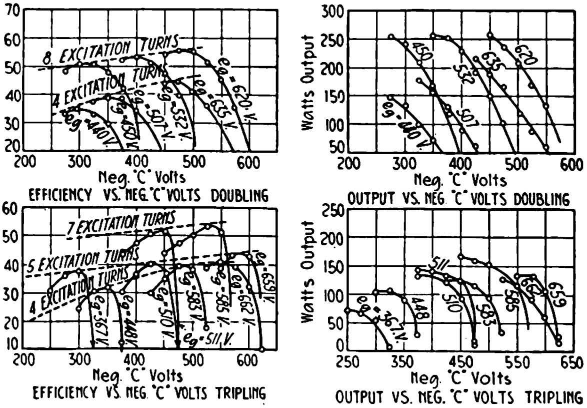

Fig. 3

and another critical adjustment for maximum output. As the order of multiplication is increased, these adjustments become more critical and the points of maximum efficiency and maximum output more nearly coincide. The curves of Fig. 3 illustrate these points. It will be noted also that higher efficiency as well as greater output is obtained for higher values of excitation voltage.

Fig. 4 shows graphically the relation between negative "C" voltage and excitation voltage at maximum efficiency. One horizontal line is obtained from each curve of Fig. 3. The line *AB* is an arbitrary reference line. The point *C* indicates the grid biasing voltage at the point of maximum efficiency for the excitation voltage represented by the length of the line *CD*. The d-c plate-current grid-voltage characteristic of the quarter kw tube used is dotted in to give an idea of pro-

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portions. Even ignoring the fact that the dynamic blocking voltage is considerably greater than that shown in the static characteristic, it is at once evident that Fig. 1 is not a true representation of the conditions shown in Fig. 4, for plate current obviously is flowing for longer periods of time than one-half of one cycle of output voltage. The condition may be more nearly approximated in the curves of Fig. 5, and suggests the possibility of regenerative feed-back in the amplifier.

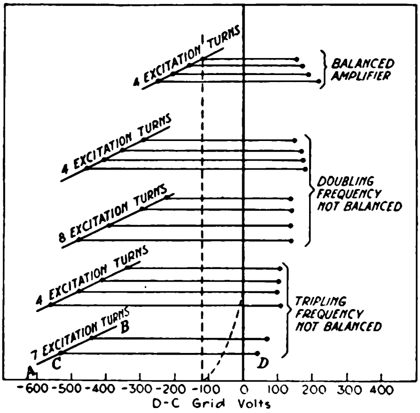

Fig. 4

A study of the connections of the circuit (Fig. 2) will show that with a very small number of excitation turns the reactance of the grid circuit of the amplifier to the output frequency will be inductive, inasmuch as the inductance of these turns is in parallel with the small grid-ground capacity with respect to the feed-back e.m.f.

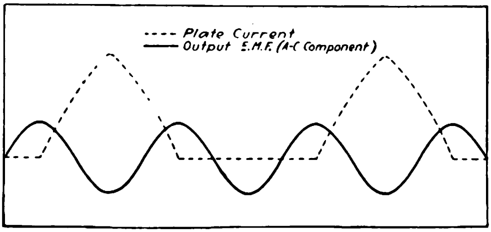

Fig. 5

This is the condition for regeneration in the amplifier. With very few excitation turns the reactance is relatively small and the regeneration slight. If turns are increased, reactance and regeneration will increase until the amplifier goes into self oscillation and the crystal

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control is lost. The presence of such regeneration would account for the increased plate current noted.

If this interpretation is correct, increasing the excitation turns should greatly increase the efficiency and output of the amplifier, and the change should produce a noticeable increase in grid current. The curves of Fig. 3 show decidedly higher efficiencies and outputs with increased excitation turns. Accompanying these higher values a radio-frequency current in the amplifier grid circuit of two and three amperes was noted instead of one-tenth to five-tenths ampere as observed with few excitation turns. This verification seems to indicate beyond all doubt that practical frequency multiplication in this type of circuit depends largely upon regeneration in the amplifier. This regeneration is obtained for the most part through internal feed-back capacity of the tube and can be varied by changing the grid-circuit reactance. By proper adjustment of this reactance the efficiency of the multiplier can be made to approach the efficiency of the ordinary balanced amplifier. It will be noted from Table I that an efficiency of 70 per cent was ob-

TABLE I

Frequency	Input	Plate Dissipation	Output	Efficiency
4000 kc	326 watts	81 watts	245 watts	75 per cent
(Singling)	412 "	121 "	291 "	71 "
8000 kc	433 "	154 "	279 "	64.5 "
(Doubling)	570 "	206 "	364 "	63.8 "
12000 kc	256 "	76 "	180 "	70.4 "
(Tripling)	507 "	267 "	240 "	42.3 "

tained for tripling frequency as compared to 75 per cent for singling. The same efficiency for doubling could not be obtained by the method used, for the required number of excitation turns is too great for sufficient energy transfer from the master oscillator.

In the light of these conclusions, reasons for the inferiority of the screened grid tube for frequency multiplying are obvious. The extremely small effective plate-grid feed-back capacity reduces the regeneration to a minimum, while the low grid-ground capacity reduces the inductive reactance of the grid circuit. Values obtained with the quarter-kw screened-grid tube type AT671 are given in Table II. Operation of the circuit with this type of tube can be considerably improved by increasing the excitation turns and adding a small capacity between plate and grid. At best, however, it can only approach the conditions of the triode, and always with lower efficiency due to shield dissipation.

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When this type of circuit is used in high power transmitters the problem of self oscillation becomes more serious, due to stray coupling between amplifier stages. A reduction in excitation turns accomplishes the double purpose of reducing grid-circuit reactance to prevent self oscillation, and diminishing the reaction of the amplifier back on the crystal oscillator. This does not necessarily mean a sacrifice of regeneration since the stray feed-back may be considerable, but in practice regeneration and efficiency are sacrificed in the interests of stability.

Although high efficiencies were obtained in the amplifier when tripling, the output was less than that obtained when doubling or singling. In order to obtain more output at high efficiency on triple frequency the power of the oscillator must be increased, since in tripling only a small part of this power is useful in driving the amplifier.

TABLE II

Frequency	Input	Plate and Shield Dissipation	Output	Efficiency
4000 kc	574 watts	193 watts	381 watts	66.5 per cent
(Singling)	662 “	245 “	417 “	63. “
8000 kc (Doubling)	539 “	303 “	236 “	44. “
12000 kc (Tripling)	370 “	210 “	160 “	44. “

When singling, the whole output of the oscillator is effective on the amplifier grid. In doubling frequency only about half the output is effective, since the amplifier is blocked during the negative half of every cycle. The output of the oscillator must therefore be practically doubled to get the same effective power delivered to the amplifier grid. For higher orders of multiplication the effective portion of the oscillator output is correspondingly less, so that more output from the oscillator is necessary to produce the same output from the amplifier. The resulting inefficient use of the oscillator output at higher orders places a practical limit on multiplication per stage at about three. Where higher frequencies are desired the system can be extended into two or more multiplying stages.

This work was undertaken under the supervision of A. Crossley, formerly of the Naval Research Laboratory, now of the Steinite Radio Corporation. The writer wishes to acknowledge with thanks the assistance of J. Warren Wright.

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Books Received

Elements of Radio Communication, by John H. Morecroft, professor of electrical engineering, Columbia University. Published by John Wiley and Sons, Inc., 1929. 270 pages, illustrated, 6×9 inches, cloth binding. Price, $3.00 Contents: simple laws of the electric circuit; special laws for radio circuits; general idea of radio communication; the vacuum tube and its uses; radio telegraphy; radio telephony; receiving sets; problems.

Introduction to Theoretical Physics, by Leigh Page, Ph.D., professor of mathematical physics, Yale University. Published by D. Van Nostrand Company, Inc.,1928. 587 pages, illustrated. 6×9 inches, buckram binding. Price $6.50. Contents: vector analysis; dynamics of particles; dynamics of rigid bodies; dynamics of deformable bodies; advanced dynamics; hydrodynamics of perfect fluids; hydrodynamics of viscous fluids; classical thermodynamics; statistical mechanics; kinetic theory of gases; electrostatics and magnetostatics; electric currents; electromagnetic theory; geometrical optics; physical optics; origin of spectra.

Radio Manual, 1928 edition revised by Commander F. W. Rockwell, Lieutenant C. W. Brewington, and Professor G. D. Robinson all of the department of electrical engineering and physics, U.S. Naval Academy. Published by U.S. Naval Academy. 176 pages, $7\frac{3}{4}\times10\frac{1}{2}$ inches, cloth binding. Price $3.50. Contents: wave motion; resistance, inductance, capacity and resonance; simple oscillating circuit; use of simple frequency meter; apparatus for damped wave transmission; transmission of continuous waves; radiation of waves; receiving apparatus; vacuum tube as a detector; vacuum tube as an amplifier; screen-grid tube; regeneration, feed-back; multistate amplification; three-element vacuum tube as transmitter; radio telephone transmitter; antennas; coil antennas; beam transmission; interference and selectivity; naval radio apparatus; standard symbols and definitions (I.R.E.).

Radio—A Study of First Principles, by Elmer E. Burns, Instructor in Physics, Austin High School, Chicago, Ill. Published by D. Van Nostrand Company, Inc., 255 pages, illustrated. Price, $2.00. Contents: simple receiving circuits; electric batteries; magnetic action of an electric current; electric circuits and Ohm's law; electron tubes; alternating currents; detectors and amplifiers; fundamentals of receiving circuits; oscillating and transmitting circuits; radio measurements; appendix.

Storage Batteries—Theory, Manufacture, Care and Application, by Morton Arendt, assistant professor of electrical engineering, Columbia University. Published by D. Van Nostrand Company, Inc., 1928. 285 pages, illustrated. Cloth binding. Price, $4.50. Contents: introduction and history; general theory of the storage battery; lead plates and their manufacture; sulphuric acid electrolyte; factors influencing capacity and efficiency; lead storage cell parts and assembly; installation, operation and maintenance; the nickel-iron-alkaline cell; storage battery testing; storage battery applications.

Practical Television, by E. T. Larner, engineering department, General Post Office, London. Published by D. Van Nostrand Company, Inc., 1928. 175 pages, $5\frac{1}{4}\times8\frac{1}{2}$, illustrated, cloth binding. Price, $3.75. Contents: introduction; history; selenium and the selenium cell; continental and American researches; researches with the cathode-rays; images and their formation; the Baird televisor; television technique; recent developments; appendix.

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Proceedings of the Institute of Radio Engineers
Volume 17, Number 9 *September, 1929*

MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R100 Duncan, R. L. and Drew, C. E. Radio telegraphy and telephony (book). Publisher: J. Wiley and Sons, New York, N. Y. 1929.

(A textbook for students of radio.)

R113 Nakai, T. On the difference of East to West and West to East transmission phenomena at sunrise and sunset. Researches Electrotechnical Lab., Tokyo, #241; November, 1928. Original in Japanese. Abstract in *Experimental Wireless and W. Engr.* (London), **6**, p. 323; June, 1929.

(From theoretical considerations based on ultra-violet radiation from sun, it was concluded that the ionized layer goes down much more rapidly after sunrise than it rises after sunset. Therefore little difference between sunrise and sunset effects should be found in East-West radio transmissions while sunrise effects should be much larger than sunset effects for West-East transmission. Data is cited in confirmation of this reasoning.)

R113.1 Parkinson, T. Some observations of short period radio fading. Proc. I. R. E., **17**, pp. 1042–1061; June, 1929.

(Causes of fading are investigated by means of graphic fading records made simultaneously with different types of receiving antennas. Evidences are found of fading due to interference; to direction shifts; to rotation of plane of polarization and to varying intensity of indirect rays; to multiple rays.)

R113.2 de Wardt, R. G. Variations in signal strength from Australia. *Post Office Elec. Engrs. Jnl.* (London), **22**, pp. 52–58; April, 1929.

(Data from systematic records of 11,660-kc transmissions from Australia as received in England are presented in graphic form. Average diurnal and seasonal variations of signal strength are shown for the twelve months of the year. Daylight-darkness effects on different portions of two transmission paths are noted.)

R113.4 Mirick, C. B. and Hentschel, E. R. A new method of determining height of the Kennelly-Heaviside layer. Proc. I. R. E., **17**, pp. 1034–1041; June, 1929.

(Periodic variations of fairly constant frequency over a considerable time interval are shown in graphic records of radio signals transmitted from a high-frequency aircraft transmitter. From geometric considerations of this frequency, the ground speed of the plane, and the transmitting distance, the effective height of the layer is computed.)

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R113.5 Maurain, Ch. Sur l'origine de certains parasites. (On the origin of certain atmospherics) *L'Onde Electrique*, **8**, pp. 131–134; April, 1929.

(The value of making observations of the connection between radio disturbances, electromagnetic phenomena, and meteorological conditions as a study of the relations between the meteorological and electrical properties of the atmosphere, is stressed.)

R113.5 Bureau, R. Sur l'origine de certains parasites. (On the origin of certain atmospherics) *L'Onde Electrique*, **8**, pp. 135–142; April, 1929.

(Arguments in favor of a meteorological origin of night atmospherics are summarized. The theory is offered that atmospherics of the afternoon are the effect of a strong meteorological situation and not of the storm itself.)

R113.5 Maurain, Ch. Sur l'orage magnetique du 7 au 8 Juillet, 1928 et les phenomenes connexes. (On the magnetic storm of July 7–8, 1928 and connected phenomena). *L'Onde Electrique*, **8**, pp. 170–172; April, 1929.

(Reports concerning sunspots, radio transmission and aurora displays attending the magnetic storm of July 7–8, 1928 are summarized.)

R131 Average characteristics of amplifier tubes with a.c. filament supply. *Radio* (San Francisco), **11**, p. 46; July, 1929.

(Data on tubes.)

R132 Brainard, J. C. Mathematical theory of the four-electrode tube. Proc. I. R. E., **17**, pp. 1006–1020; June, 1929.

(The mathematics of the four-electrode tube including in the most general case expressions for the plate and two grid currents in terms of the applied voltages in the two-grid circuits and the impedances of all three circuits, are given. To avoid complexity the general expression is reduced to illustrative specific cases.)

R132 Aughtie, F. Push-pull amplification—The use of resistance-capacity coupling. *Experimental Wireless and W. Engr.* (London), **6**, pp. 307–309; June, 1929.

(A circuit is described in which use is made of the phase reversal of a simple resistance-capacity coupled stage to feed the grid of the second tube of the output pair of a push-pull amplifier. A transformer is therefore not needed and adjustment for maximum power output is simple.)

R134 Reed, M. The problem of turn-over. *Experimental W. and Wireless Engr.* (London), **6**, pp. 310–315; June, 1929.

(A mathematical explanation of the difference in output currents from a rectifier with the same a.c. input but with connections reversed is given. Conditions for a minimum difference are summarized and the application of the results to the design of vacuum-tube voltmeters is pointed out.)

R150 Beauvais, G. A. Sur les ondes de 10 a 20 centimetres. (On waves of 10 to 20 centimeters). *Bull. de la Soc. Française des Electriciens*, **9**, pp. 503–510; May, 1929.

(Production of very high frequencies by means of a circuit arrangement by Pierret is given, with difficulties encountered in the generation of such frequencies. Application of these frequencies to radiotelephony and radiotelegraphy is discussed.)

R190 Carson, J. R. Reciprocal theorem in radio communication. Proc. I.R.E. **17**, pp. 952–956; June, 1929.

(An analysis of Rayleigh's reciprocity theorem and the Sommerfeld-Phrang reciprocity theorem shows them to be distinct in their practical field of application. The latter theorem is shown to have restrictions seriously limiting its field of applicability.)

R190 Pelabon, H. Application dela theorie electronique aux mauvais contacts. (Application of electron theory to bad contacts). *L'Onde Electrique*, **8**, pp. 160–170; Apr., 1929.

(With the help of the electron theory the expressions for the intensity of a direct current and of an alternating current in a circuit containing an imperfect contact are deduced. Rectification by a contact between identical metals in which one electrode is movable is explained. A study of effects of electromagnetic impulses shows the phenomena of coherence with an imperfect contact to be due to the displacement of the electrodes. An idea on Branley's negative coherence in PbO_2 is given.)

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R200. Radio Measurements and Standardization

R220 Bligh, N. R. Measurements of the grid-anode capacity of screen-grid valves. *Exp. Wireless and W. Engr.* (London), **6**, pp. 299–300; June, 1929.

(Measurements of the grid-anode capacities of the screen-grid tubes of the S625 and S215 type give an average for the former of 0.022 $\mu\mu$f and for the latter of 0.014 $\mu\mu$f.)

R220 Loughren, A. V. and Parker, H. W. The measurement of direct inter-electrode capacitance of vacuum tubes. Proc. I. R. E., **17**, pp. 957–65; June, 1929.

(A method of measuring direct capacitance in the range of 10^{-10} to 10^{-16} farads by a charging current at radio frequencies is described. The circuit is arranged to provide apparatus giving results measured visually by the substitution of a standard.)

R270 Hollingworth, J. and Naismith, R. A portable radio intensity measuring apparatus for high frequencies. *Exp. Wireless and Wireless Engr.* (London), **6**, pp. 316–318; June, 1929.

(Circuit for apparatus to measure radio field intensities in the range 12000 to 4547 kc (25–66 meters) is described. It includes a local oscillator, an attenuator in the form of a resistance voltage divider, and a heterodyne receiving set and a rectifying unit for measuring the output.)

R300. Radio Apparatus and Equipment

R325.1 A new direction finder for naval vessels. *Jnl. Scientific Instruments* (London), **6**, pp. 201–202; June, 1929.

(Type D.F.M.4 direction finder developed by Research Dept. of Marconi Co. for use on naval vessels. Set is used for taking bearings on CW, ICW, spark or phone stations and has a frequency range of 75–1000 kc (300–4000 meters)).

R330.4 Hodgson, B., Harley, L. S., and Pratt, O. S. The development of the oxide-coated filament. *Jnl.* I. E. E. (London), **67**, p. 762; June, 1929.

(Reviews development of oxide-coated filament. Describes in rough outline present day methods of manufacture for commercial purposes and indicates most recent views on mechanism of electron emission from alkaline earth oxides.)

R341 Gas-filled rectifying valves. *Experimental Wireless and W. Engr.* (London), **6**, pp. 291–292; June, 1929.

(The tubes developed by A. W. Hull of the General Elec. Co. for the rectification of large alternating currents are described and an explanation of the thermionics involved is given.)

R342 Engel, F. H. Engineering features of the UX-245. *Radio Broadcast*, **15**, pp. 167–168; July, 1929.

(Characteristics of tube as power amplifier.)

R342.15 Radio-frequency transformers as applied to screen-grid valves. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 293–298; June, 1929.

(Under simplified assumptions expressions giving (1) the overall voltage amplification, and (2) the conditions for stability, are derived for a screen-grid tube between a tuned circuit and a r-f transformer with its secondary tuned. If the primary turns of the transformers are reduced to give the requisite stability, results comparable with those from a neutralized triode may be obtained from a good commercial screen-grid tube without the complications of a neutralized circuit.)

R342.5 Spitzer, E. E. Grid losses in power amplifiers. Proc. I. R. E., **17**, pp. 985–1005; June, 1929.

(The experimental results of a study of the driving power of a power-amplifier at 60 cycles are presented. The power input to the grid is shown to be proportional to the d-c grid current raised to the 1.34th power and to be practically independent of grid bias voltage if grid current is kept constant. The study extends to six types of commercial air-cooled transmitting tubes. Effects of primary and secondary electron emission by the grid on the driving power are considered.)

R343 Colebrook, F. M. A selective 8-valve receiver for medium and long

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wave telegraphy. *Jnl. Scientific Instruments* (London), **6**, pp. 177–183; June, 1929.

(A receiving set which was designed for the Meteorology Department of the National Physical Laboratory, London, for recording of time signals on frequencies of 200 to 15 kc is described. The principal requirements were met in this set and were: (a) comparative ease of manipulation; (b) sufficient sensitivity and selectivity for the signal operation of a relay for recording purposes.)

R500. Applications of Radio

R520 Dellinger, J. H. and Diamond, H. Radio developments applied to aircraft. *Mechanical Engineering*, **51**, pp. 509–514; July, 1929.

(Description of work done by Bureau of Standards on development of a radio-beacon system which serves eight courses.)

R522 Freeman, R. H. Radiotelephony aloft. *Radio* (San Francisco), **11**, pp. 39–41; July, 1929.

(Description of work done by the Boeing Air Transport Inc. on successful plane-to-plane and plane-to-ground communication system.)

R526.1 Etudes des radiophares par le "Bureau des Standards." (Study on radio-beacons by Bureau of Standards). *L'Onde Electrique*, **8**, pp. 143–159; April, 1929.

(A summary of the work on radio beacons for aircraft carried on at the Bureau of Standards up to November 6, 1928.)

R550 Eckersley, P. P. and Howe, A. B. The operation of several broadcast stations on the same wavelength. *Jnl.* I. E. E. (London), **67**, pp. 772–789; June, 1929.

(Consideration is given to the advantages to be derived from operation of several broadcasting stations on one wavelength and to means whereby such operation may be attained. A brief outline is given of theory of production of distortion of various types inherent to single wavelength operation. A theory is elaborated to account, quantitatively, for amount of interference from a distant station likely to be experienced when listening to a local station operating on the same wavelength. Conditions under which distortion introduced by such interference becomes negligible are determined, together with approximate service range of individual single-wave stations.)

R582 Mesny, R. Phototelegraphie d'amateur. (Amateur phototelegraphy). *Bull. de la Soc. Française des Electriciens*, **9**, pp. 511–524; May, 1929.

(Description of Belin system of phototelegraphy.)

R582 Ranger, R. H. Photoradio developments. Proc. I. R. E., **17**, pp. 966–984; June, 1929.

(A description of recent developments in photoradio apparatus is offered. Among them are: (1) a push-pull relay making possible increased speeds in transmission; (2) a reverse lead-screw for giving continuous operation of the analyzing head; (3) an air speed control eliminating certain local electrical disturbances, and (4) a hot-air recorder for use with heat sensitive paper.)

R800. Non-radio Subjects

510 Ballantine, S. Reciprocity in electromagnetic, mechanical, acoustical. and interconnected systems. Proc. I. R. E., **17**, pp. 929–951; June, 1929.

(New proof under more general assumptions than those of previous treatments, of the extension of Rayleigh's reciprocity theorem to an electromagnetic system is offered. The consideration of reciprocity is carried further into mechanical, acoustical, and interconnected systems. The concept of a transduction coefficient for use in treating interconnected systems is introduced.)

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ing, Navy Department. During Arms Conference in Washington served on advisory committee; also technical advisor to the American delegation of the International Radiotelegraph Conference in Washington, 1927. At present director of naval communications and technical advisor to the Federal Radio Commission. Associate member, Institute of Radio Engineers, 1913; Member, 1915; Fellow, 1917.

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Jenkins, C. Francis: Born 1868 near Dayton, Ohio. Attended Earlham College. Secretary to Sumner I. Kimball, U.S. Life Saving Service, Washington, D.C., 1890–1895. Built prototype of motion picture projector; developed spiral-wound paraffined all-paper container; produced first photographs by radio, mechanism for viewing distant scenes by radio, and radiomovies for home entertainment. Secured numerous patents, foreign and domestic. Maintains private laboratory in Washington, D.C. Member of the Franklin Institute, American Association for the Advancement of Science, National Aeronautic Association, founder of the Society of Motion Picture Engineers, Associate member, Institute of Radio Engineer, 1928.

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Ranger, R. H.: See PROCEEDINGS for June, 1929.

Rockwood, Warren Robert: Received B.S. degree, Rose Polytechnic Institute, Terre Haute, Ind., 1927. Student engineer, General Electric Co., 1927–1928; research laboratory, 1928 to date.

Rodwin, George: Born September 4, 1903 in New York City. Received A.B. degree, Columbia University, 1923; E.E. degree, 1925. With Radio Corporation of America doing research work in connection with fading recorder equipment, standard receiver test methods, receiver development and general broadcast station equipment, 1925 to date. Associate member, Institute of Radio Engineers, 1925.

Smith, Theodore A.: Born February 17, 1905 at Brooklyn, N.Y. Received M.E. degree, Stevens Institute of Technology, 1925. With Radio Corporation of America engaged in work on fading recording, short-wave reception, field intensity measurements, and miscellaneous work on broadcast station engineering, 1925 to date. Junior member, Institute of Radio Engineers, 1925; Associate, 1926.

Taylor, A. Hoyt: Born January 1, 1879 at Chicago, Ill. Received B.S. degree, Northwestern University; instructor, Michigan State College, 1900; instructor, University of Wisconsin, 1903. Received Ph.D. degree, University of Göttingen, Germany, 1908. Professor and head of physics department, University of South Dakota, until 1917. Lieutenant, Naval Reserve, 1917; lieutenant com-

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mander, 1918; in charge of aircraft radio laboratory, Washington, D.C., 1919; promoted to Commander, remaining in active service until 1922. Upon organization of the Naval Research Laboratory was made superintendent of its radio division. In 1927 awarded the Morris Liebmann Memorial Prize by the Institute. Member, Institute of Radio Engineers, 1916; Fellow, 1920.

Weinberger, Julius: Born July 22, 1893 in New York City. Received B.S. degree, College of the City of New York, 1913. Public Service Commission of New York, 1913–1914; radio laboratory, Bureau of Standards, 1914–1916; research assistant to Dr. A. N. Goldsmith, 1916–1917; research department, Marconi Wireless Telegraph Company of America, 1917–1919; Radio Corporation of America, 1919 to date. At present engineer in charge, research department, Radio Corporation of America. Associate member, Institute of Radio Engineers, 1913; Fellow, 1925.

Young, L.C.: Born January 12, 1891 at Danville, Ill. Amateur experimental work, 1909–1917. Telephone and Telegraph Dept., Western Division of Pennsylvania Railroad, 1912–1917. Experimental radio work, 1917–1919, under Lt. Comdr. A. H. Taylor. Aircraft radio section, Bureau of Standards, 1919; research work, radio section, Naval Research Laboratory, 1919 to date. Associate member, Institute of Radio Engineers, 1919; Member, 1929.

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